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TRANSPORTATION
INC.



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FINAL REPORT
FOR
U.S. ARMY TANK-AUTOMOTIVE COMMAND

TERRAIN SEVERITY DATA GENERATION
AT YUMA PROVING GROUND
TACOM REPORT NO. 13491

AUTHORIZATION:
CONTRACT NO. DAAE07-89-C-R106

NATC PROJECT NO. 20-17-399

OCTOBER 1989 - NOVEMBER 1990

VOLUME II OF II

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11. Sponsoring Organization Name and Address U.S. Army Tank-Automotive Command AMSTA-QAT Warren, Michigan 48397-5000 Attn: Mr. Chester Kedzior (COTR)		12. Type of Report & Period Covered Final - Volume II of II Oct 1989 - Nov 1990 14.		
15. Supplementary Notes This report consists of two volumes: Volume I contains the report narrative and supplementary charts; Volume II contains additional supplementary charts.				
16. Abstract (Limit 200 words) This report details the results of a course profiling exercise conducted at the Yuma Proving Grounds (YPG) using the Nevada Automotive Test Center (NATC) Dynamic Force Measurement Vehicle (DFMV) methodology, the U.S. Army Waterways Experiment Station (WES) rod and level methodology and the Aberdeen Proving Ground (APG) inertial profilometer methodology. The rod and level methodology was used to establish the baseline for validation and comparison purposes. Eleven test courses were profiled at YPG. The test courses profiled included terrain representative of that used by the Army for ground-based vehicle durability testing. All data acquired was supplied to the U.S. Army Tank-Automotive Command (TACOM) for further analysis by their vehicle simulation department.				
For each of the eleven courses, a left- and right-wheel path elevation versus distance profile, a left- and right-wheel path wave-number spectrum and coherence function plots were computed from the four wheels on the DFMV. This data was compared to equal data from the rod and level and the inertial profilometer.				
Based upon the profiles and wave-number spectra computed using procedures in this report, techniques for measuring and monitoring road roughness characteristics are recommended. It is further recommended that a wave-number spectrum course roughness description replace the current RMS roughness index.				
17. Document Analysis a. Descriptions road roughness, test course roughness, terrain severity, road profile, profile measurement, wave-number spectra, spatial PSD, vehicle testing, vehicle simulation				
b. Identifiers/Open-Ended Terms Dynamic Force Measurement Vehicle, U.S. Army Waterways Experiment Station rod and level, Aberdeen Proving Ground inertial profilometer, Yuma Proving Ground RMS courses, Yuma Proving Ground Middle East Courses, Yuma Proving Ground Truck Hill courses				
c. COSATI Field/Group				
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RMS COURSE #3

WAVE-NUMBER SPECTRA

2, 4, 6 and 8 MPH

Four (4) curves per speed, one for each DFMV tire, as follows

LEFT FRONT
RIGHT FRONT
LEFT REAR
RIGHT REAR

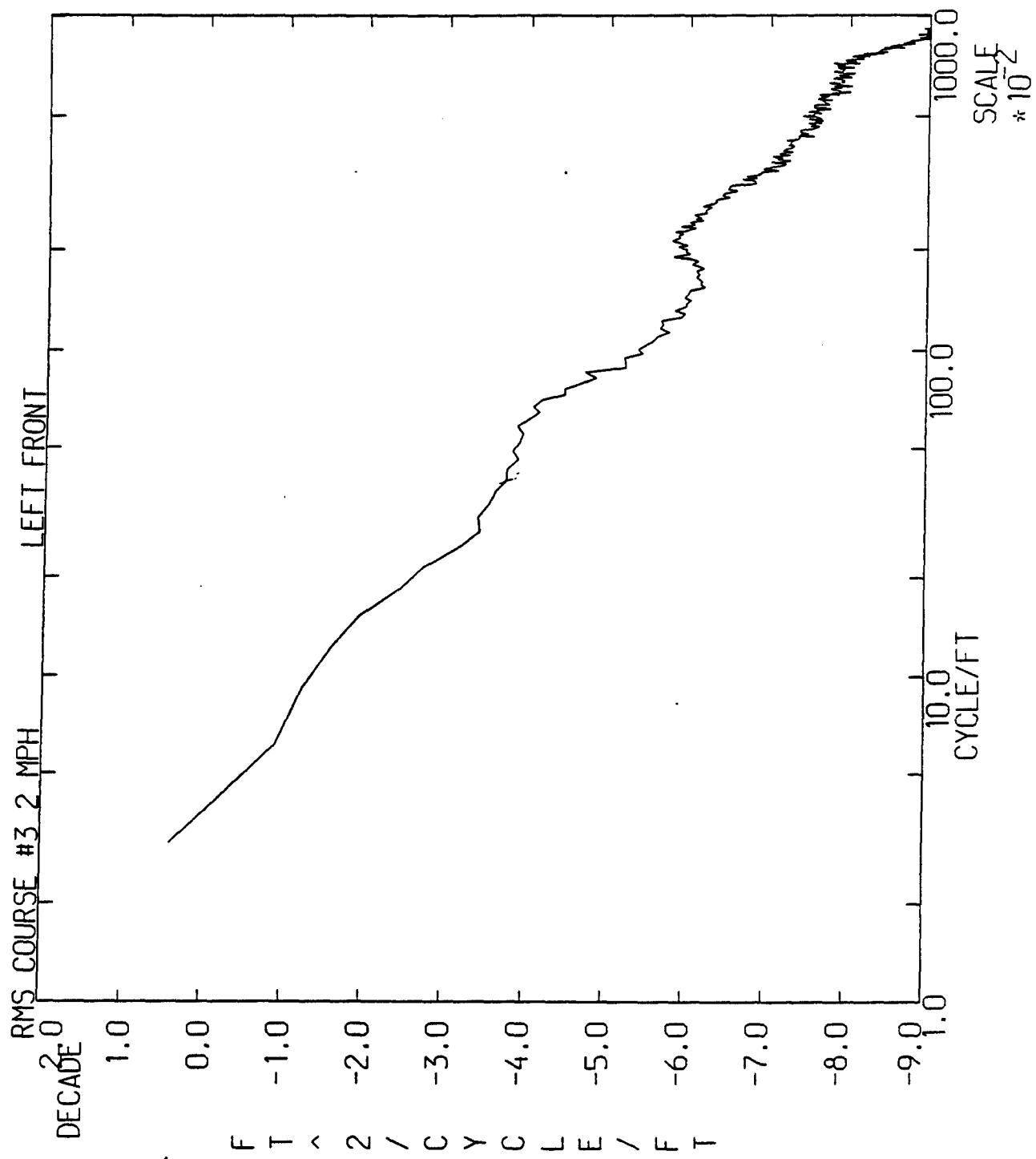
Volume II contains the data for the different DFMV speeds over each YPG course. The data was previously submitted to TACOM in an interim data report, however, the data was not reprocessed with the signal processing considerations discussed in the Volume I report (e.g., in this data, much of the spectral resolution was below the footprint). The wave-number cut-off at the low end of the spectra was limited by the frequency range of the accelerometer, as discussed in the report and shown in the table below. The wave-number cut-off at the high end of the spectrum was limited by the footprint length of the DFMV tire, which was $\approx 1.2 \text{ ft}^{-1}$. These cut-offs were verified through the DFMV front-to-rear coherence plots. Therefore, when comparing plots between different speeds, do not compare the data past these limits. As discussed in the report, the faster speed runs produced the best results at the lower wave numbers.

Table 1. DFMV Actual Versus Predicted Wavelength Limits

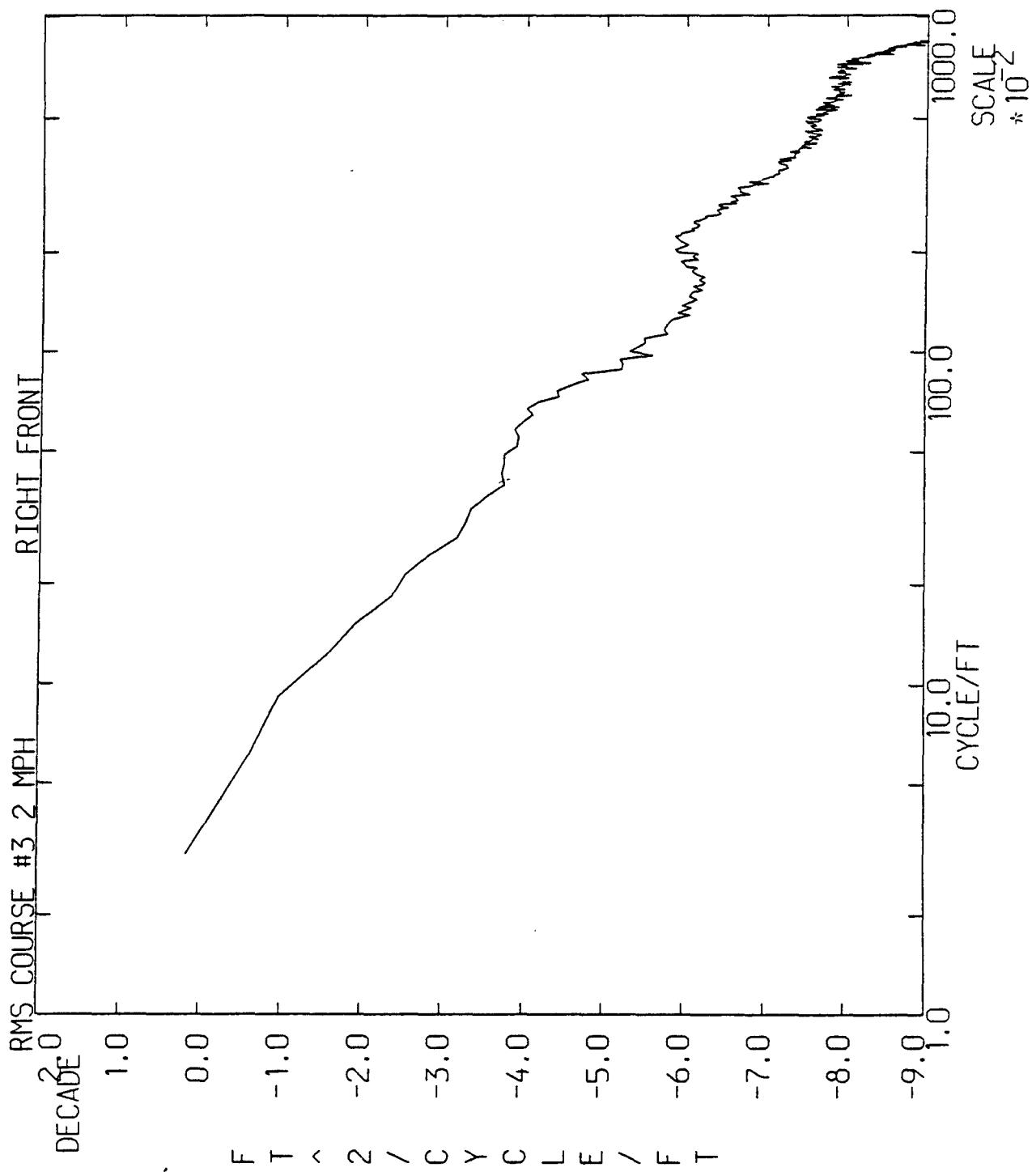
DFMV Speed MPH	Expected Wavelength Resolution*	Actual Wavelength Resolution**
2	60	15
4	120	30
6	180	45
8	240	60
10	300	75

* Based on the advertised low-end frequency range for the accelerometer used

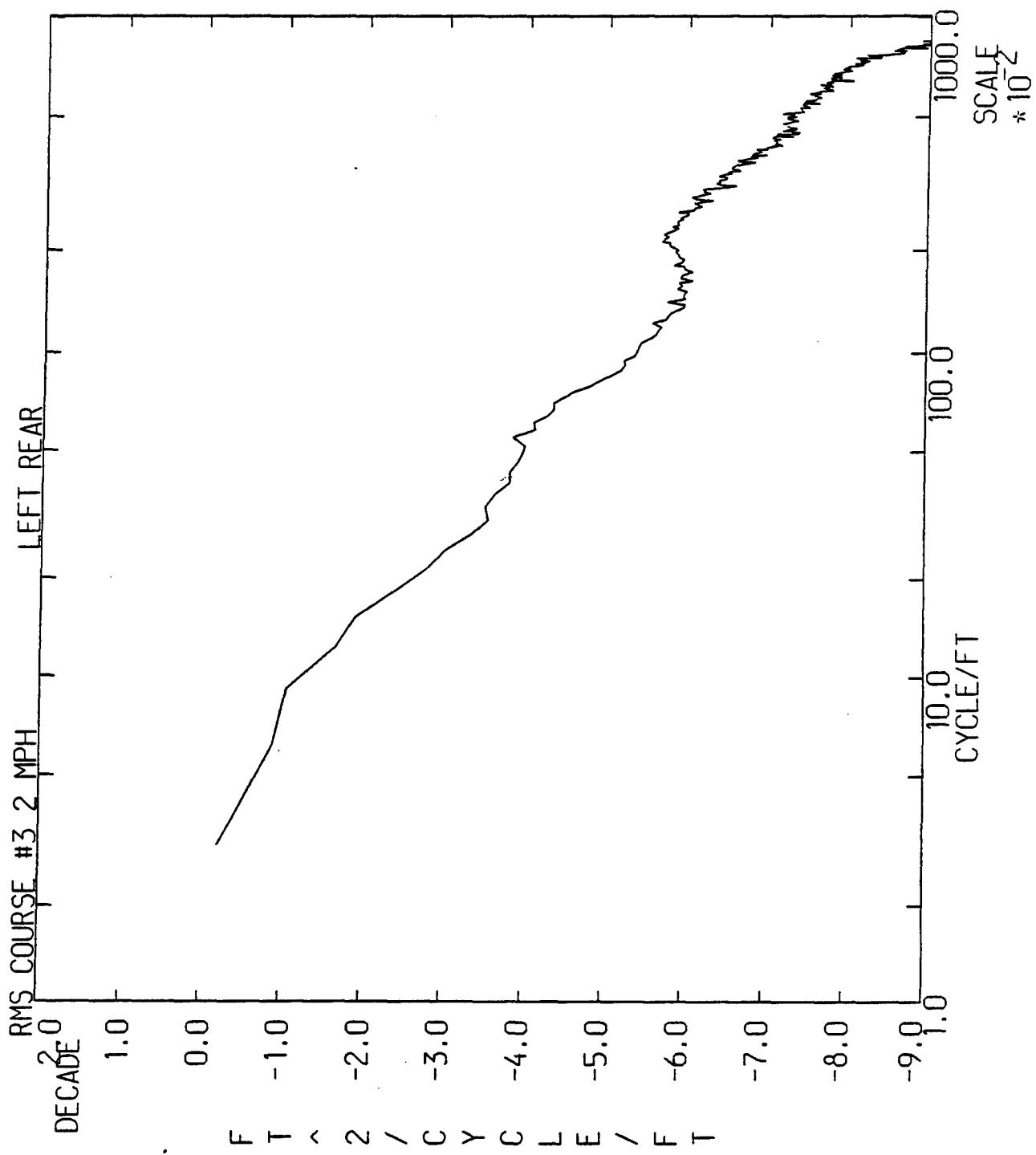
** Based on actual low-end frequency range for the accelerometer used



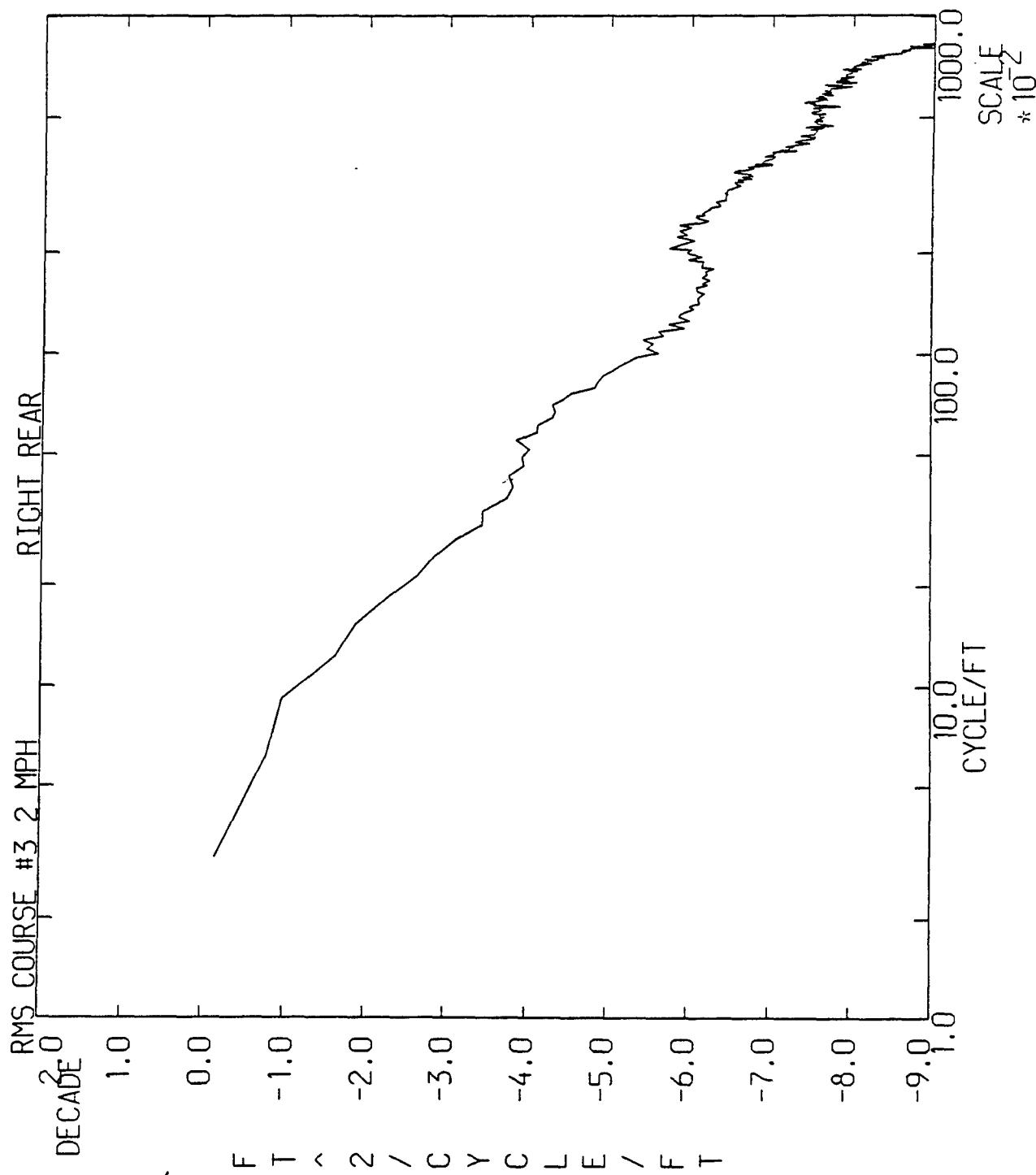
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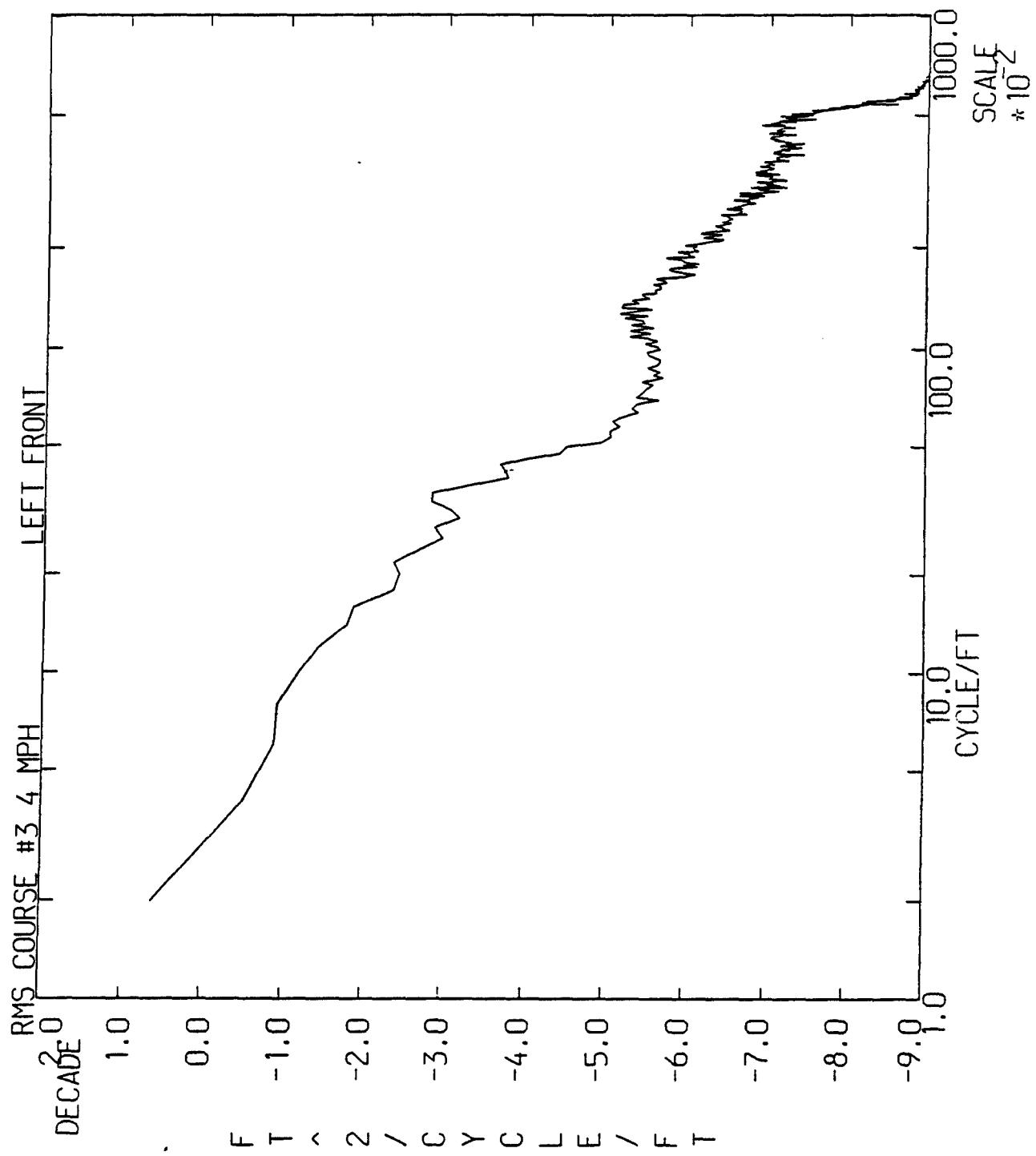
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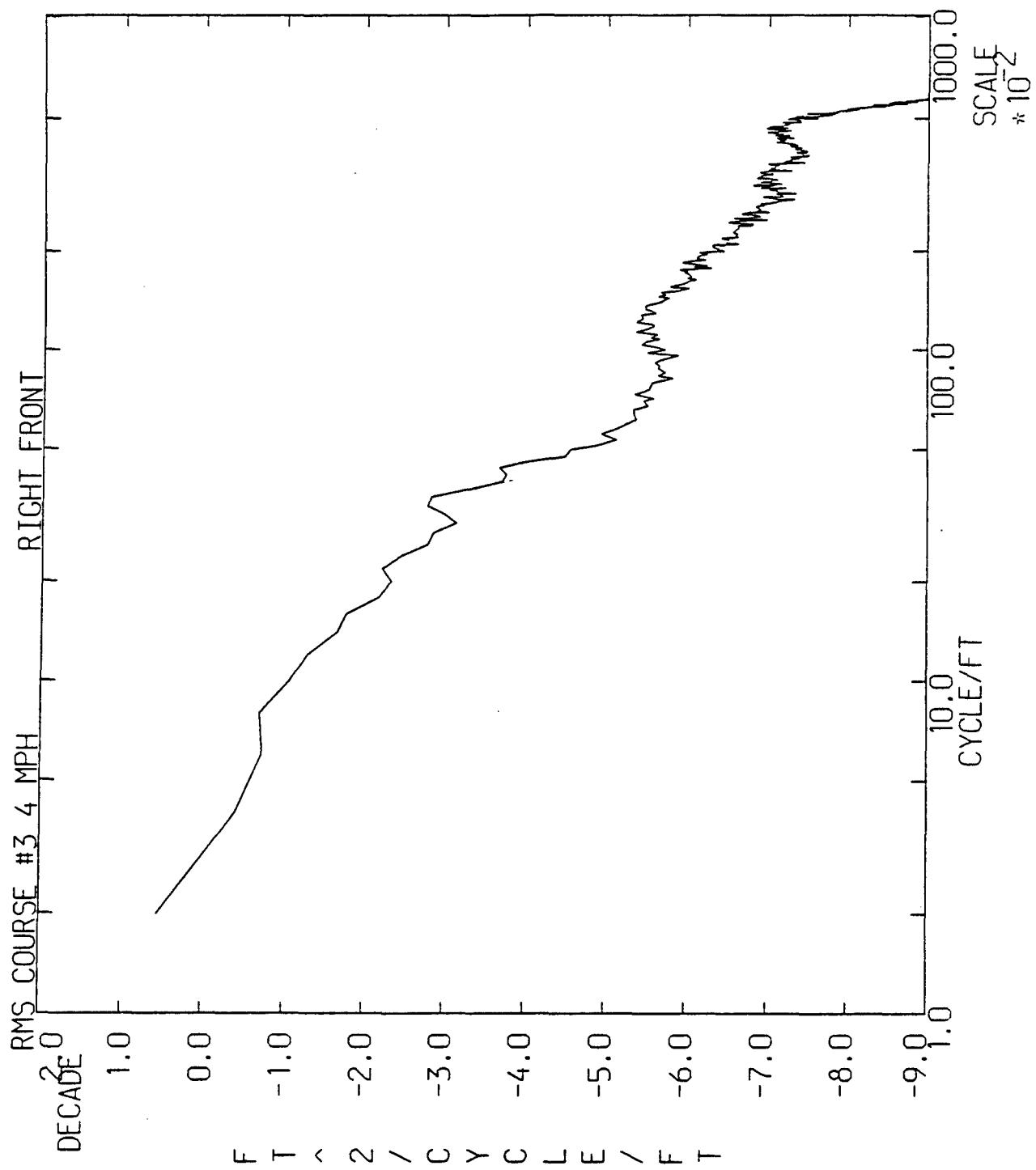
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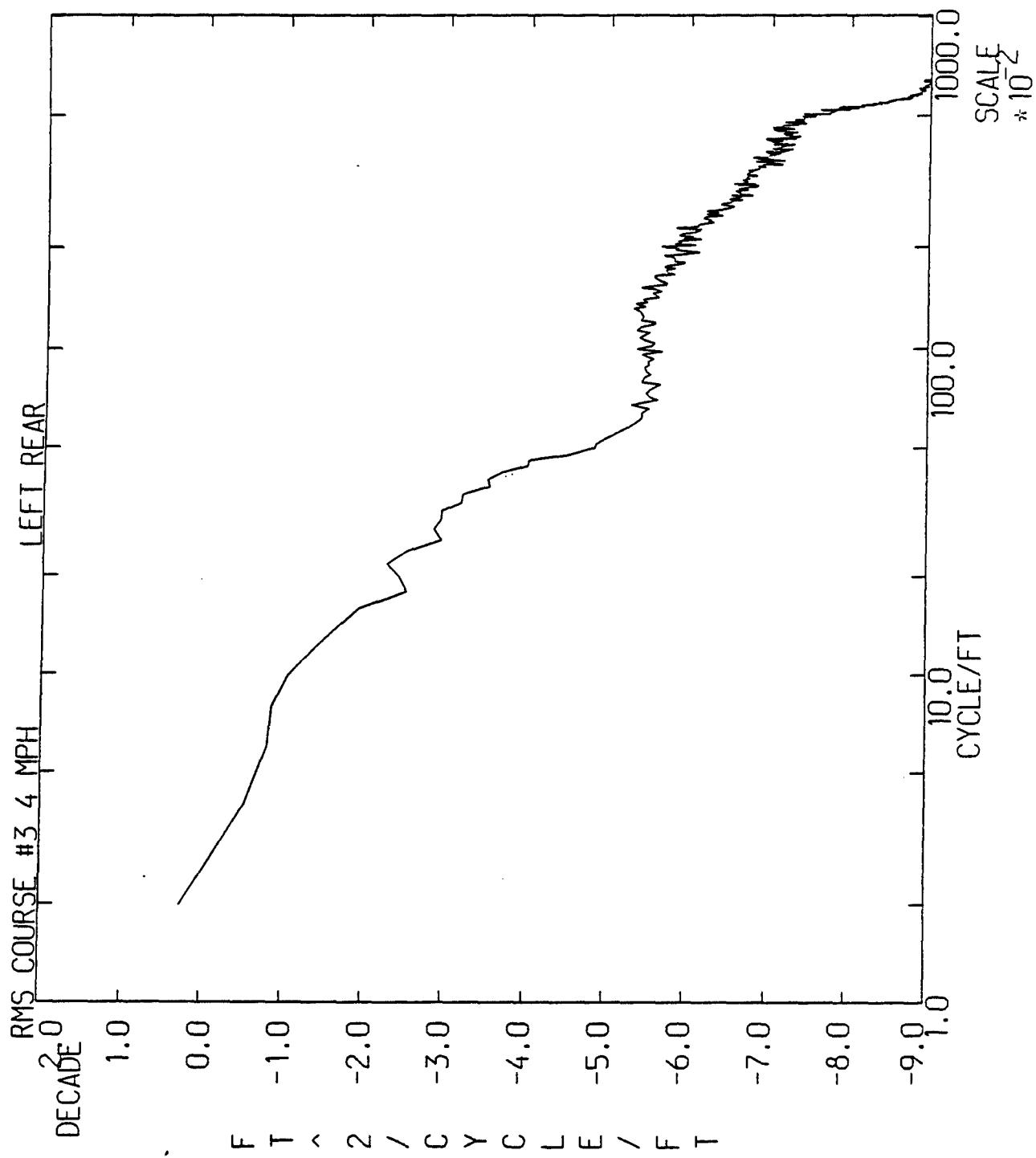


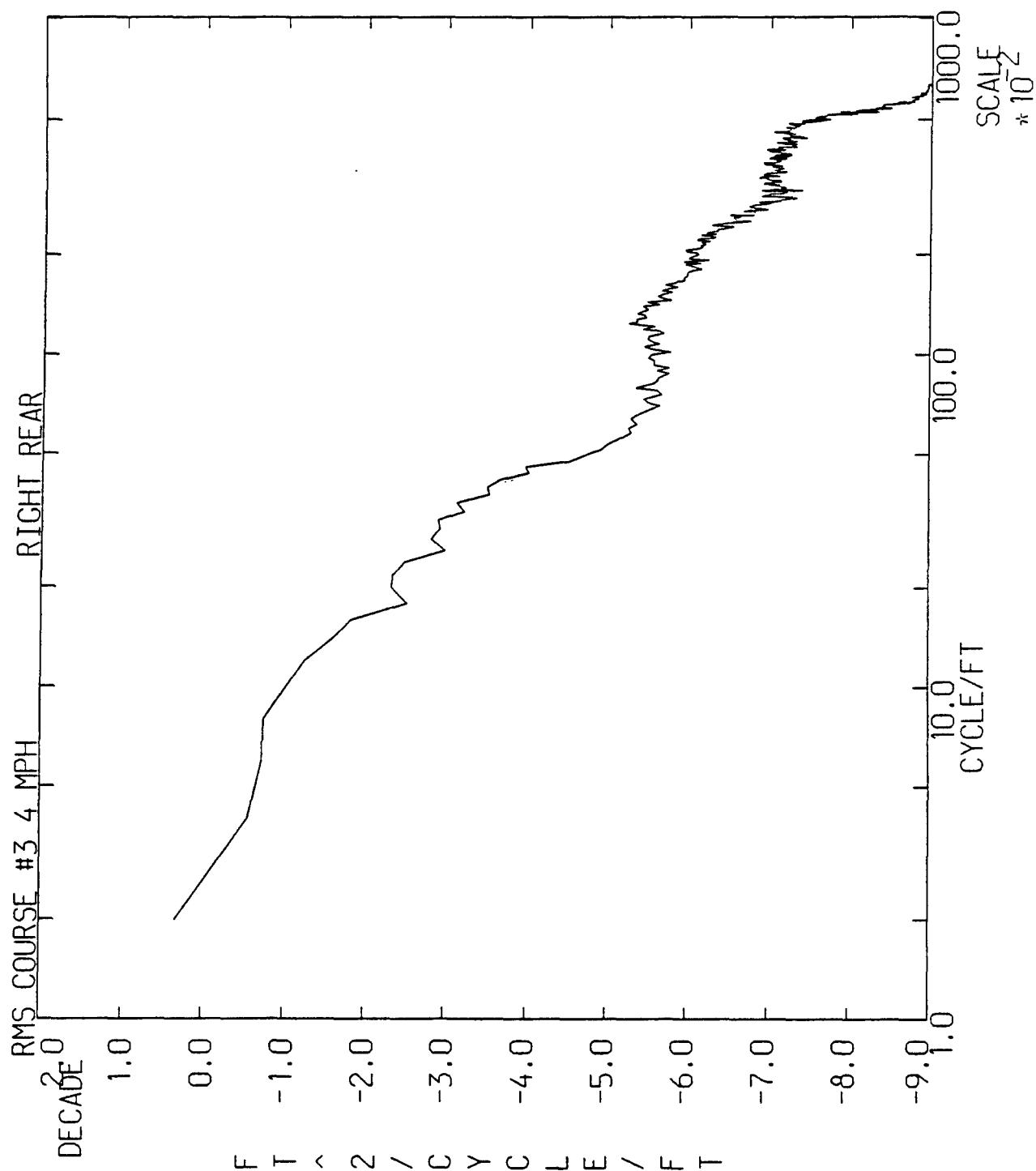
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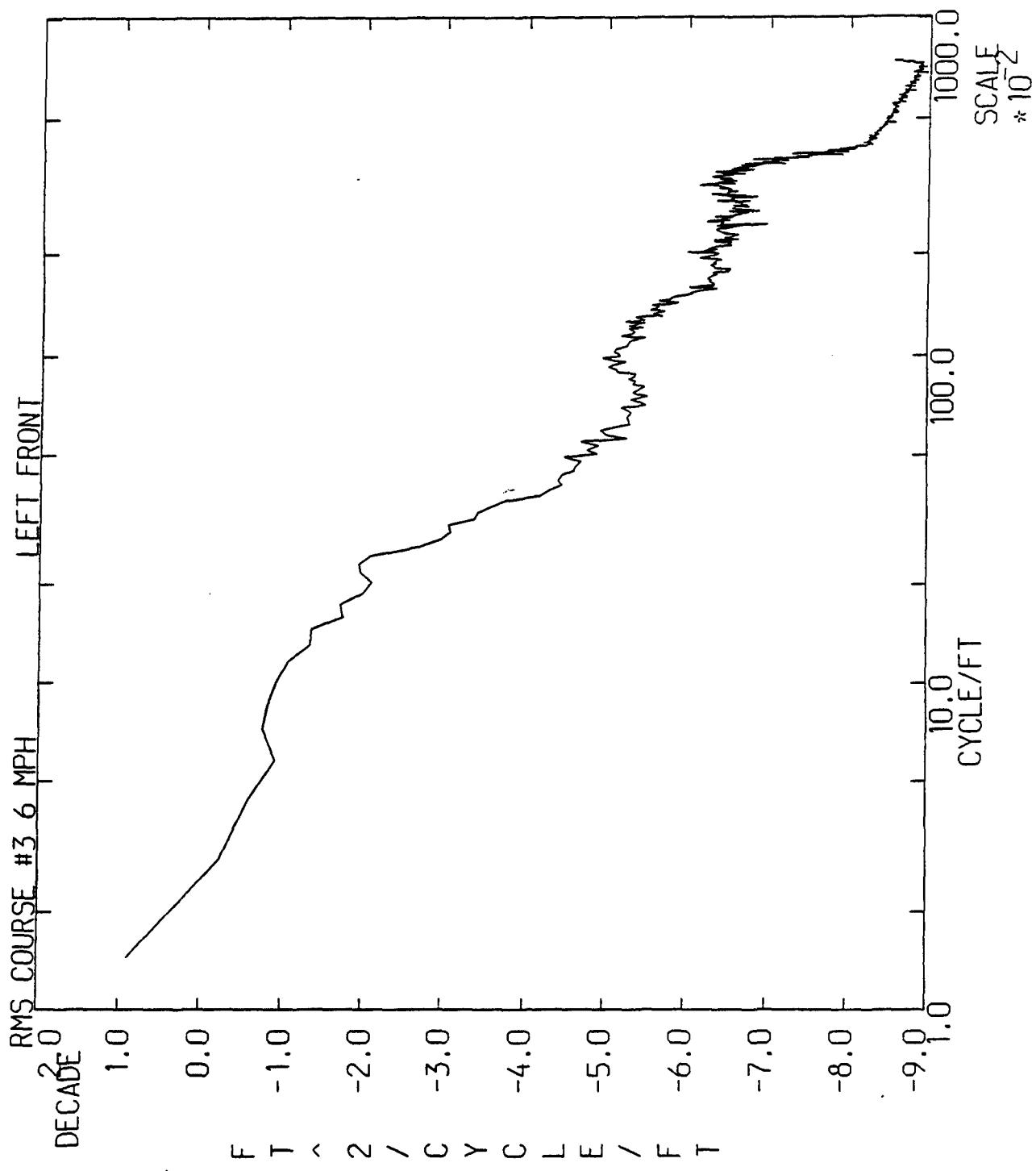
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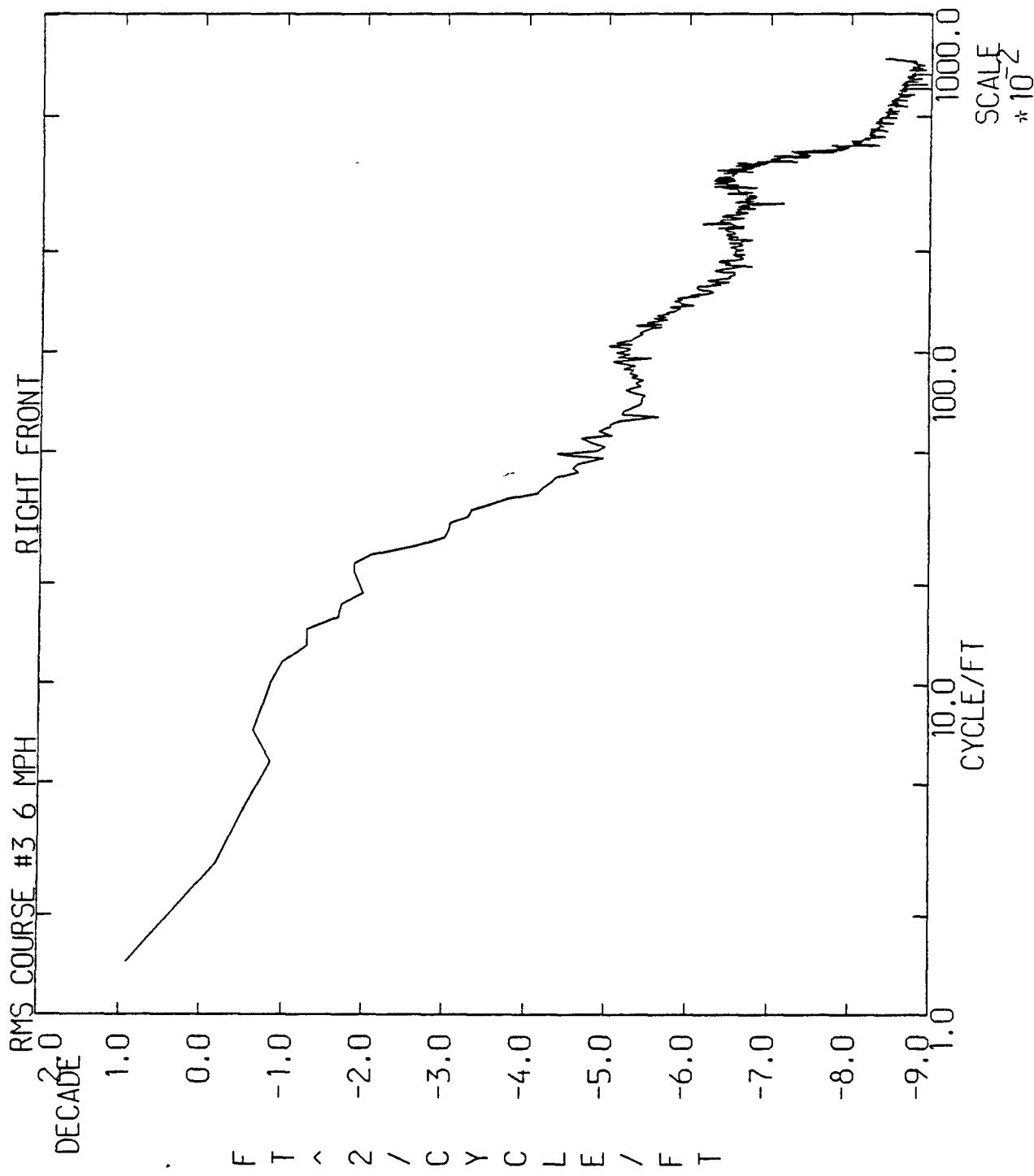


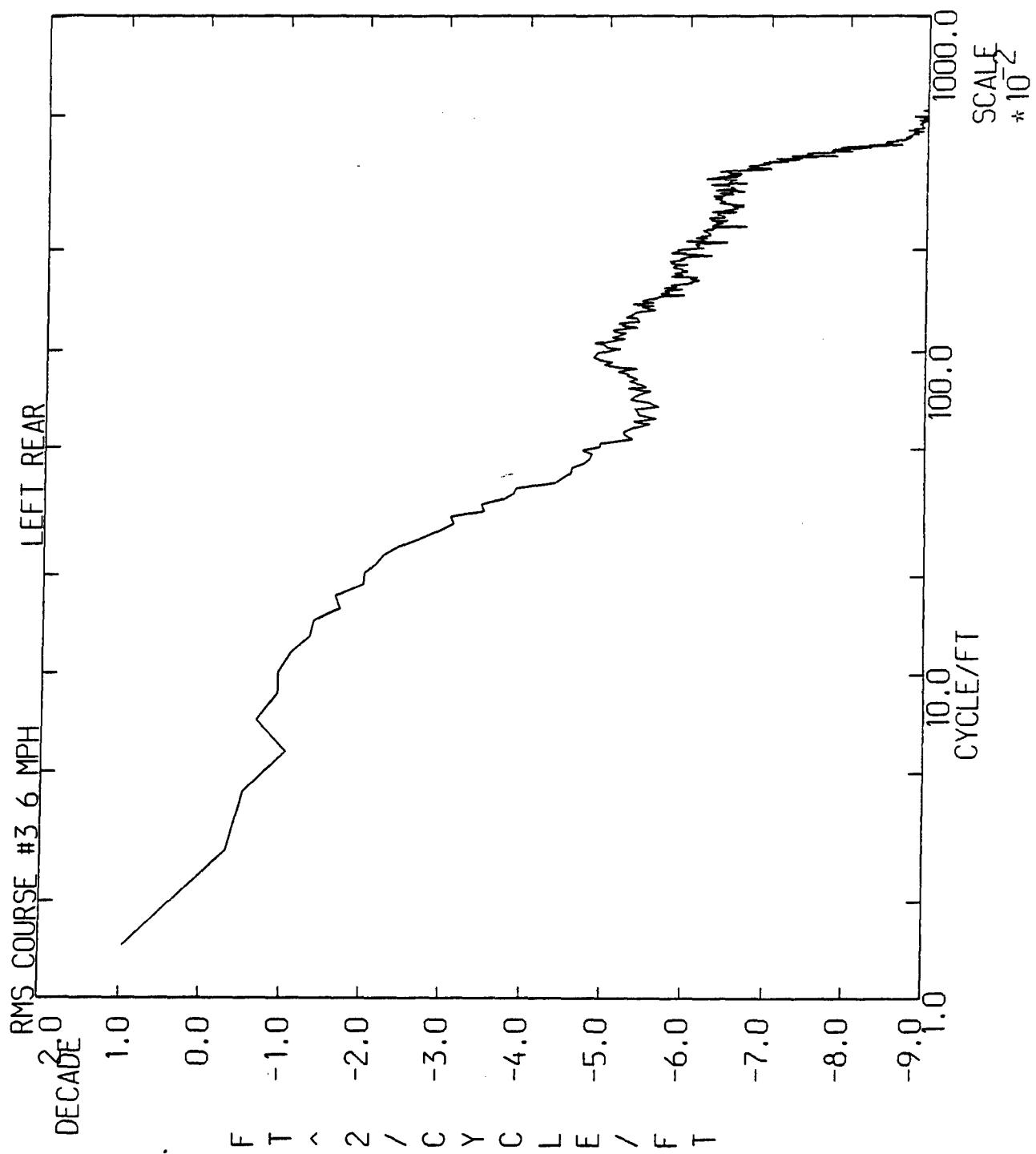


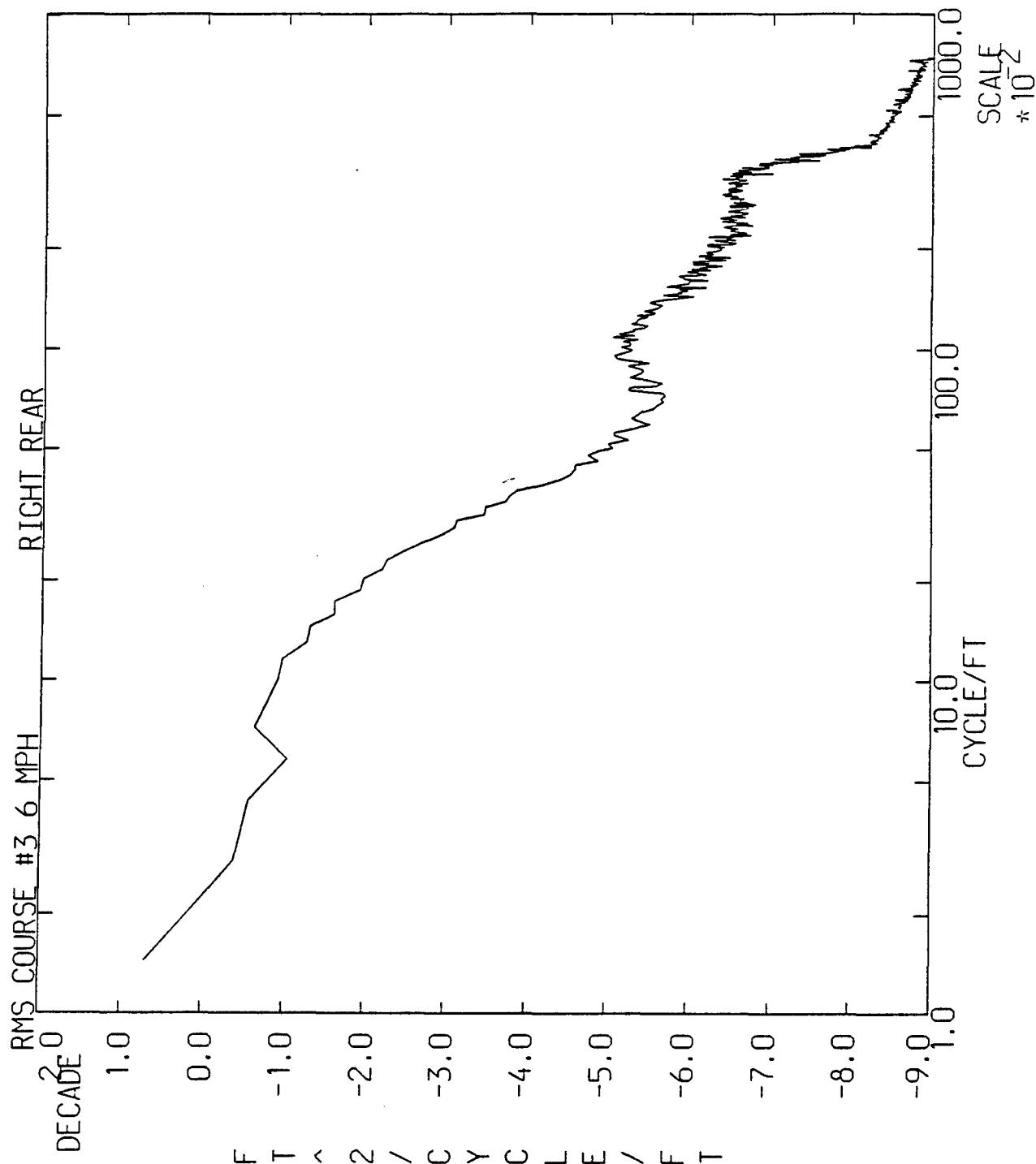


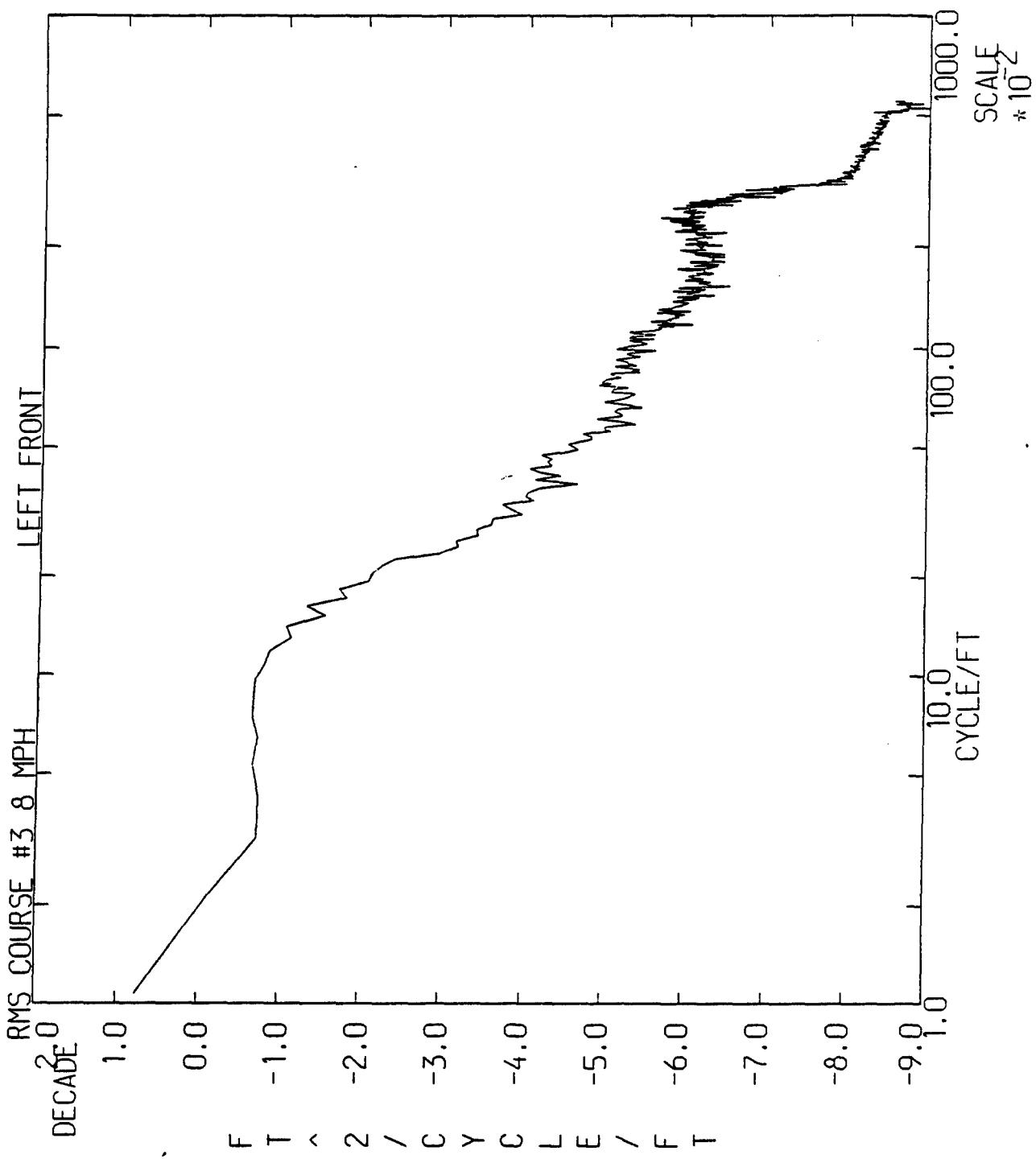
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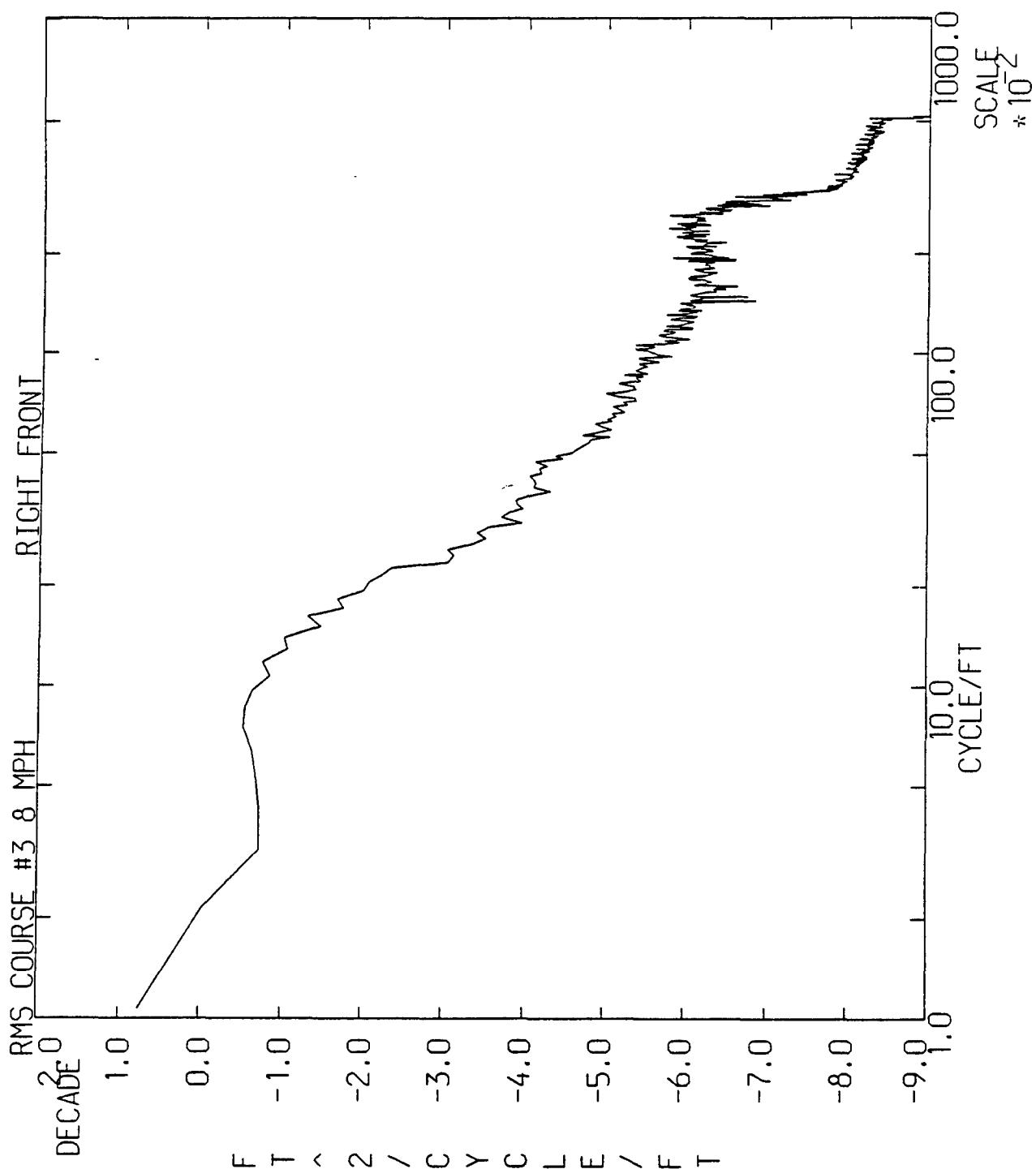




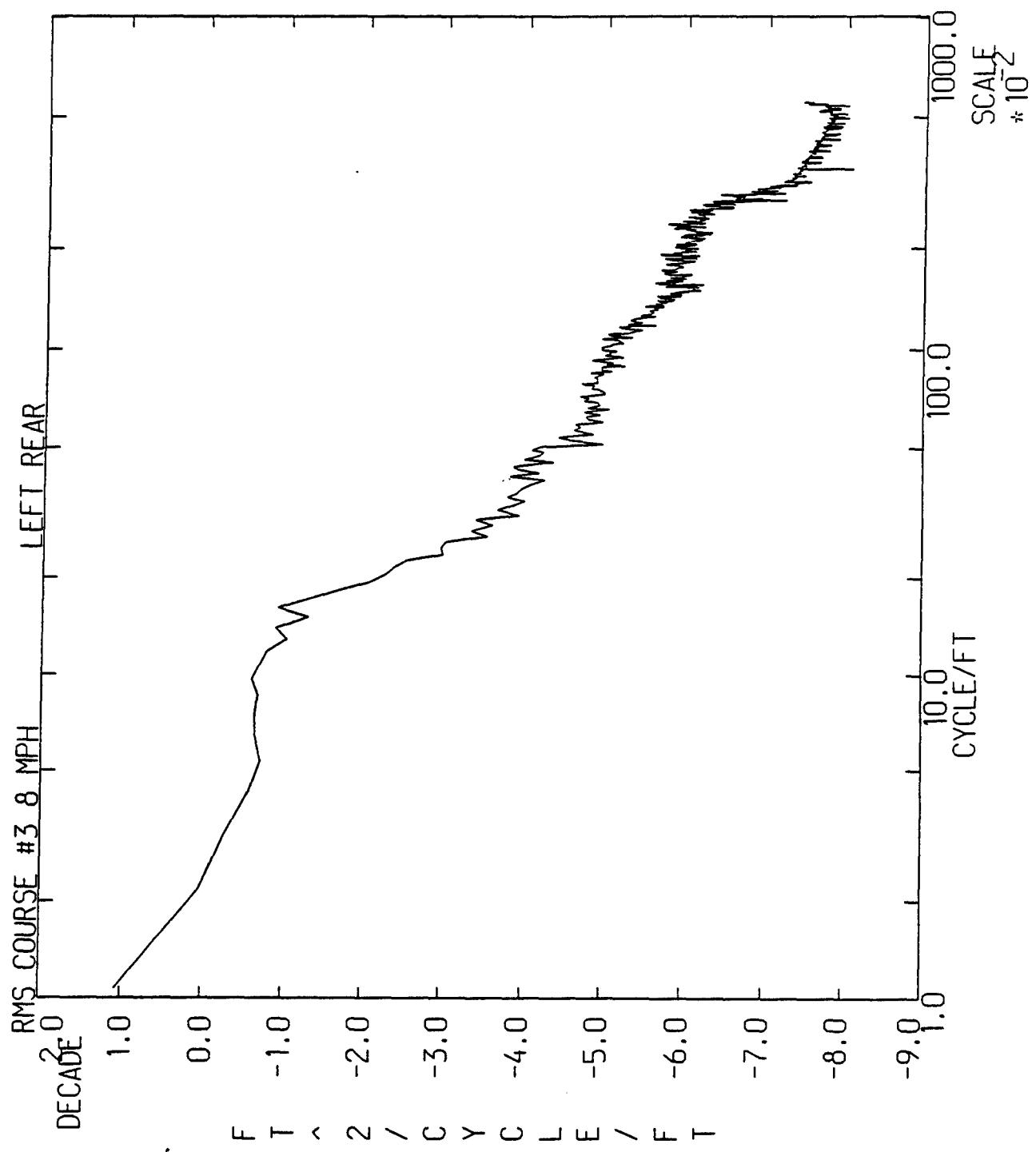




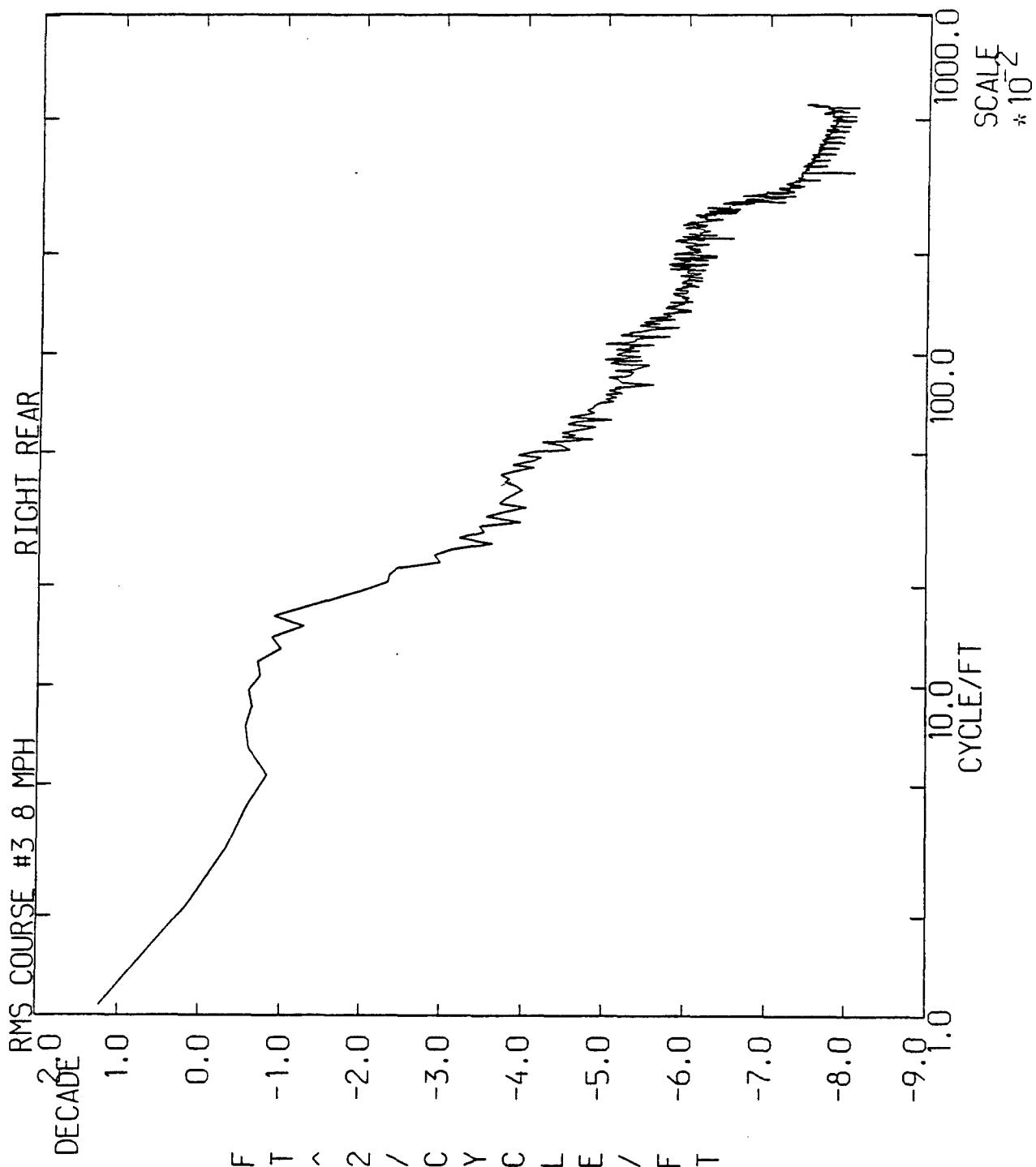




015



016



RMS COURSE #4

WAVE-NUMBER SPECTRA

2, 4, 6 and 8 MPH

Four (4) curves per speed, one for each DFMV tire, as follows

**LEFT FRONT
RIGHT FRONT
LEFT REAR
RIGHT REAR**

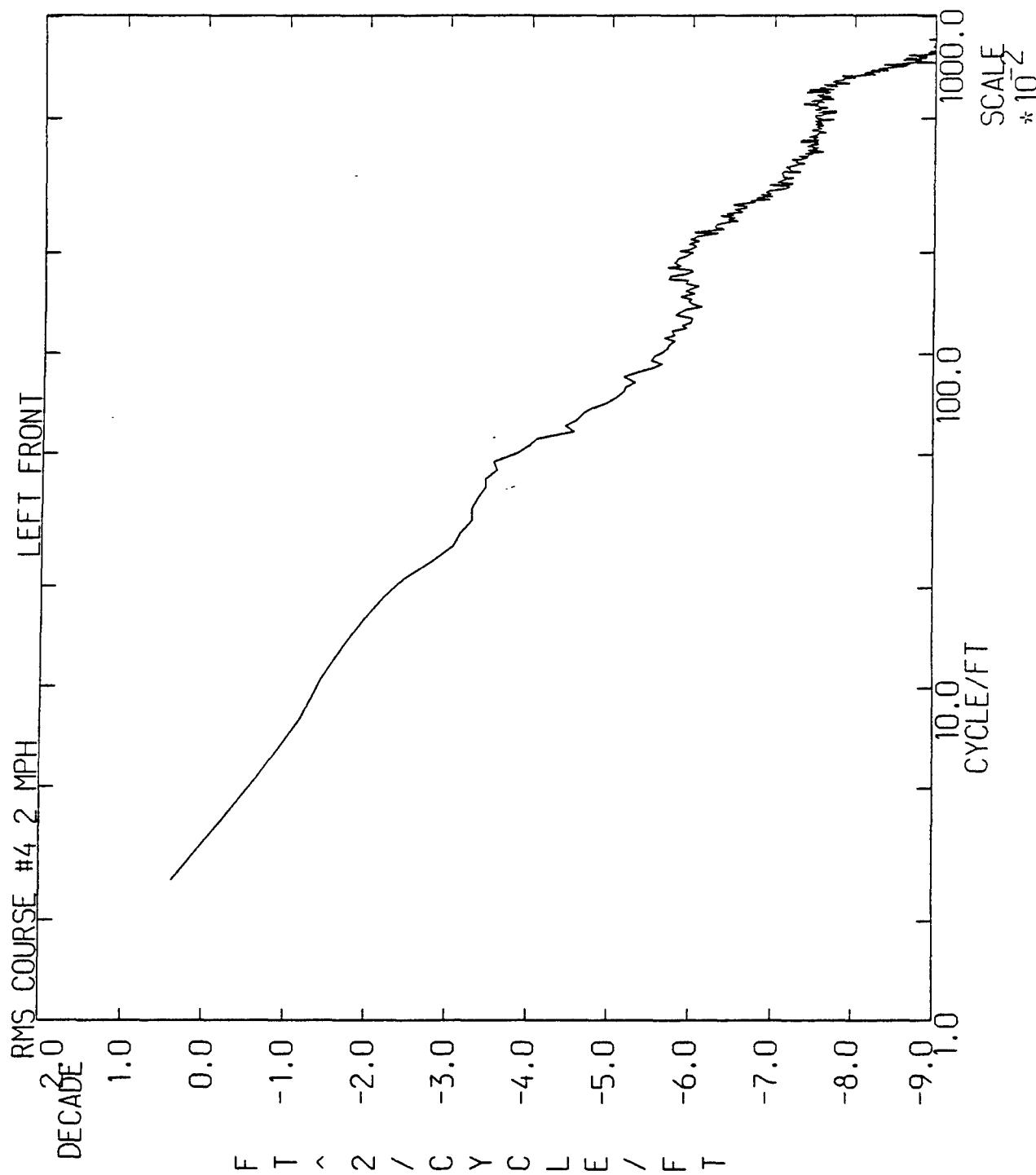
Volume II contains the data for the different DFMV speeds over each YPG course. The data was previously submitted to TACOM in an interim data report, however, the data was not reprocessed with the signal processing considerations discussed in the Volume I report (e.g., in this data, much of the spectral resolution was below the footprint). The wave-number cut-off at the low end of the spectra was limited by the frequency range of the accelerometer, as discussed in the report and shown in the table below. The wave-number cut-off at the high end of the spectrum was limited by the footprint length of the DFMV tire, which was $\approx 1.2 \text{ ft}^{-1}$. These cut-offs were verified through the DFMV front-to-rear coherence plots. Therefore, when comparing plots between different speeds, do not compare the data past these limits. As discussed in the report, the faster speed runs produced the best results at the lower wave numbers.

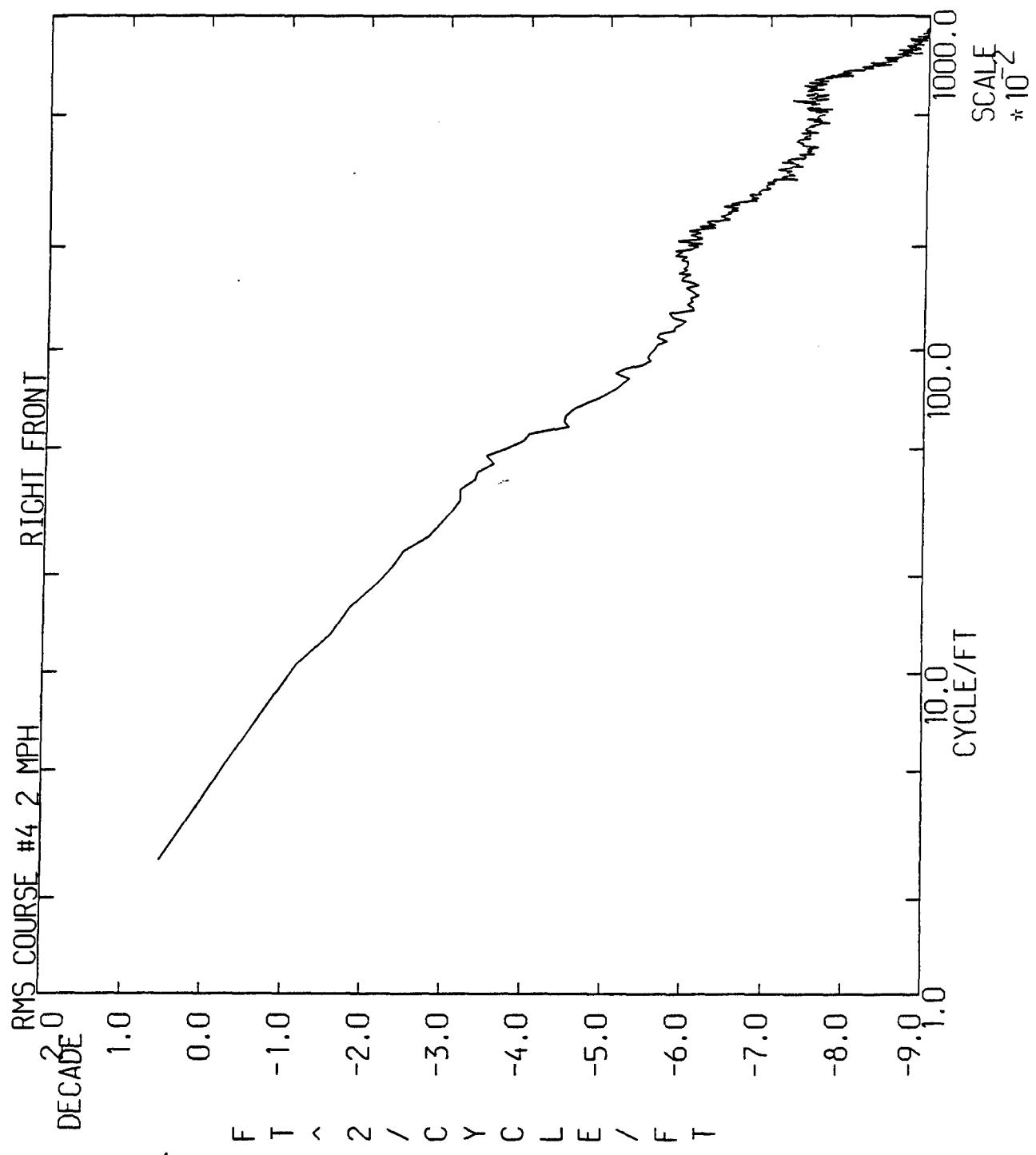
Table 1. DFMV Actual Versus Predicted Wavelength Limits

DFMV Speed MPH	Expected Wavelength Resolution*	Actual Wavelength Resolution**
2	60	15
4	120	30
6	180	45
8	240	60
10	300	75

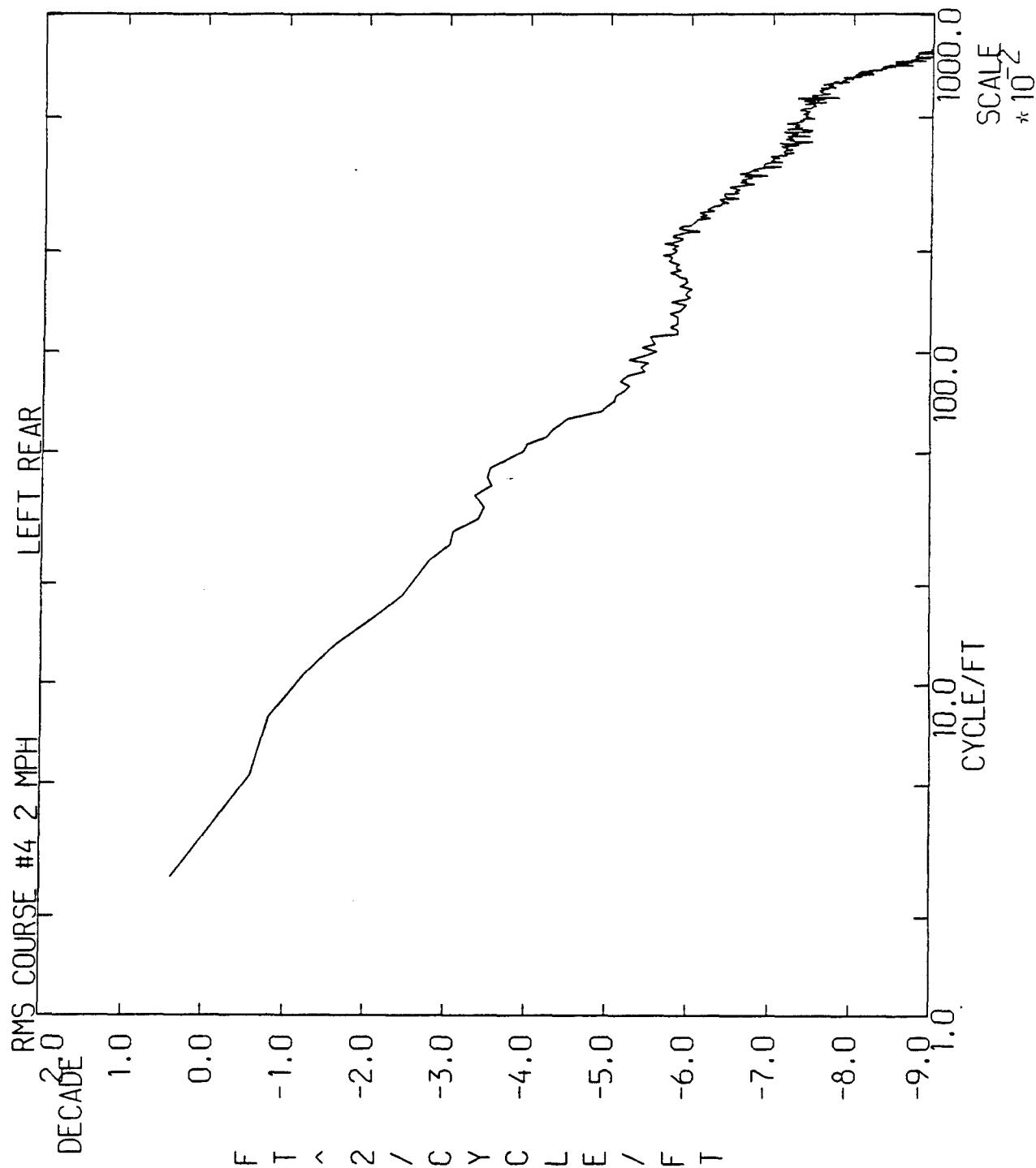
* Based on the advertised low-end frequency range for the accelerometer used

** Based on actual low-end frequency range for the accelerometer used

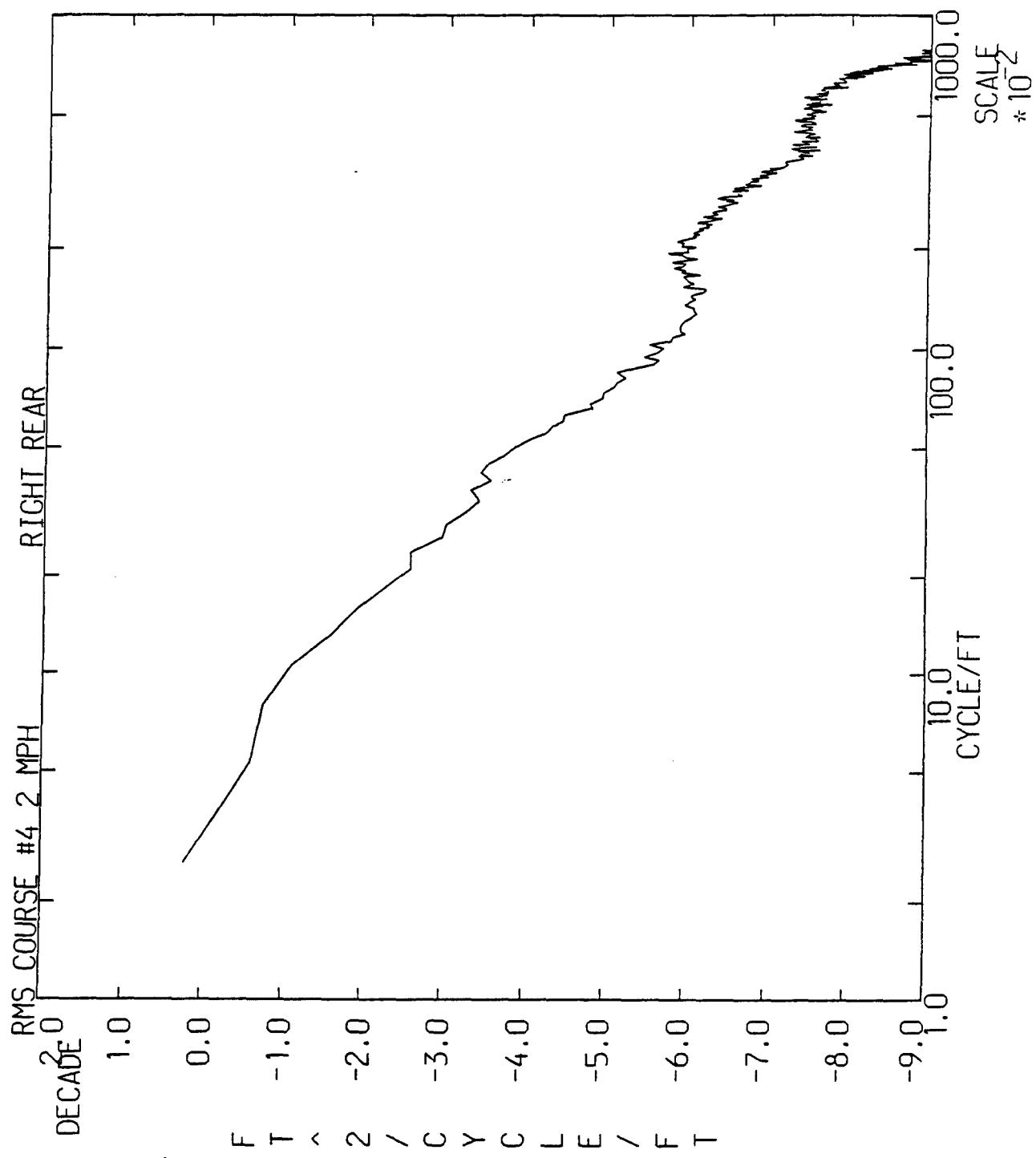


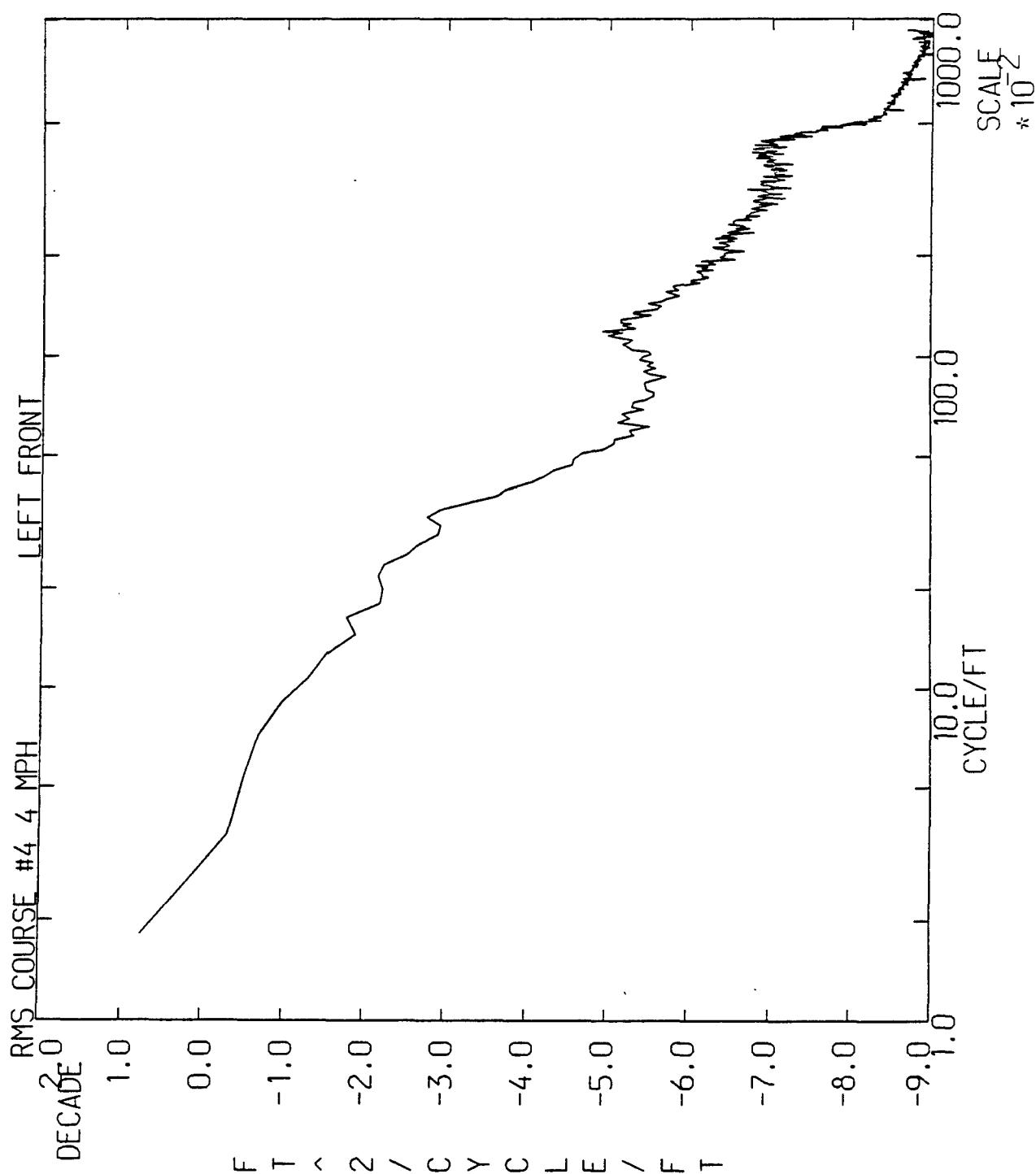


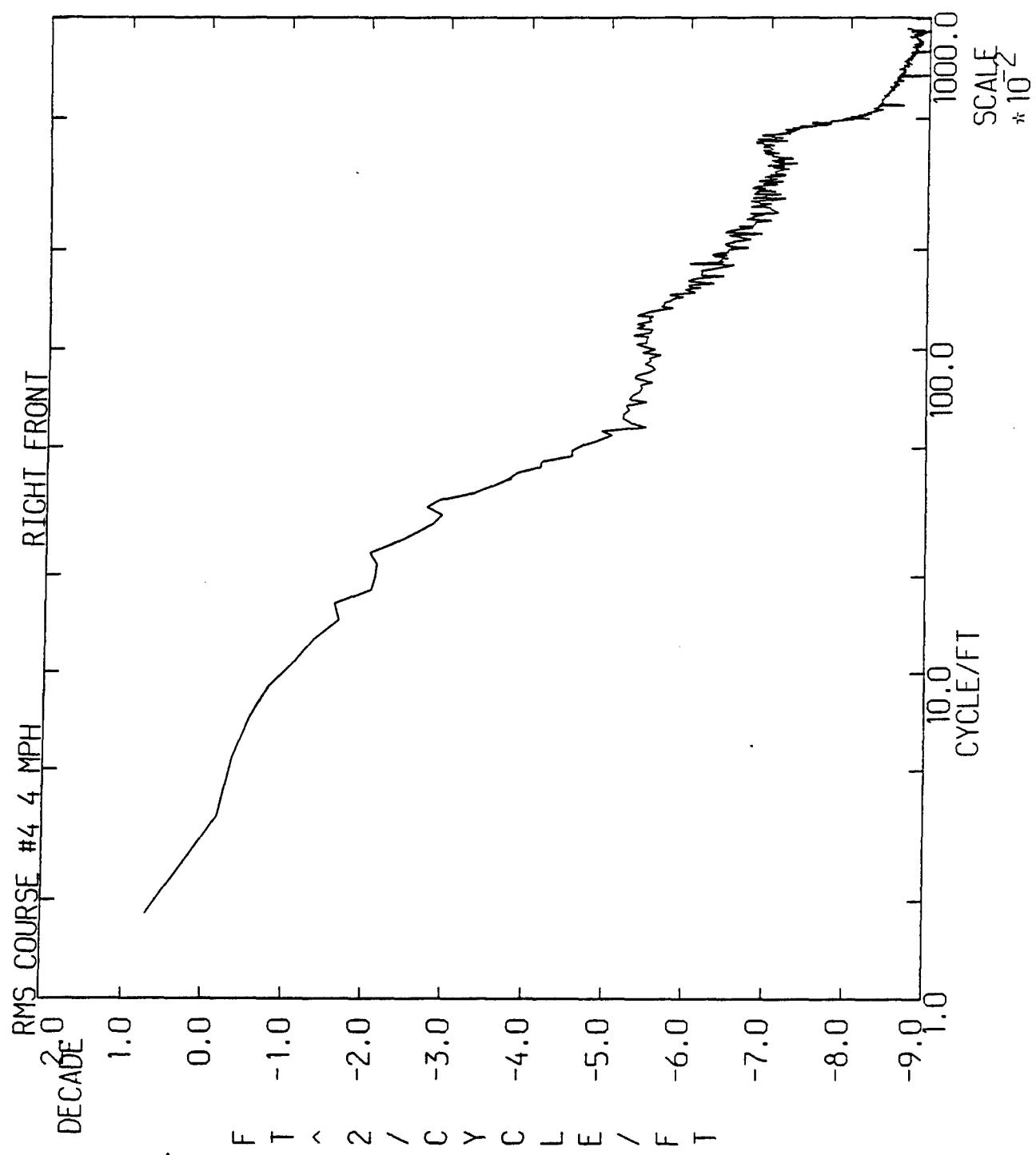
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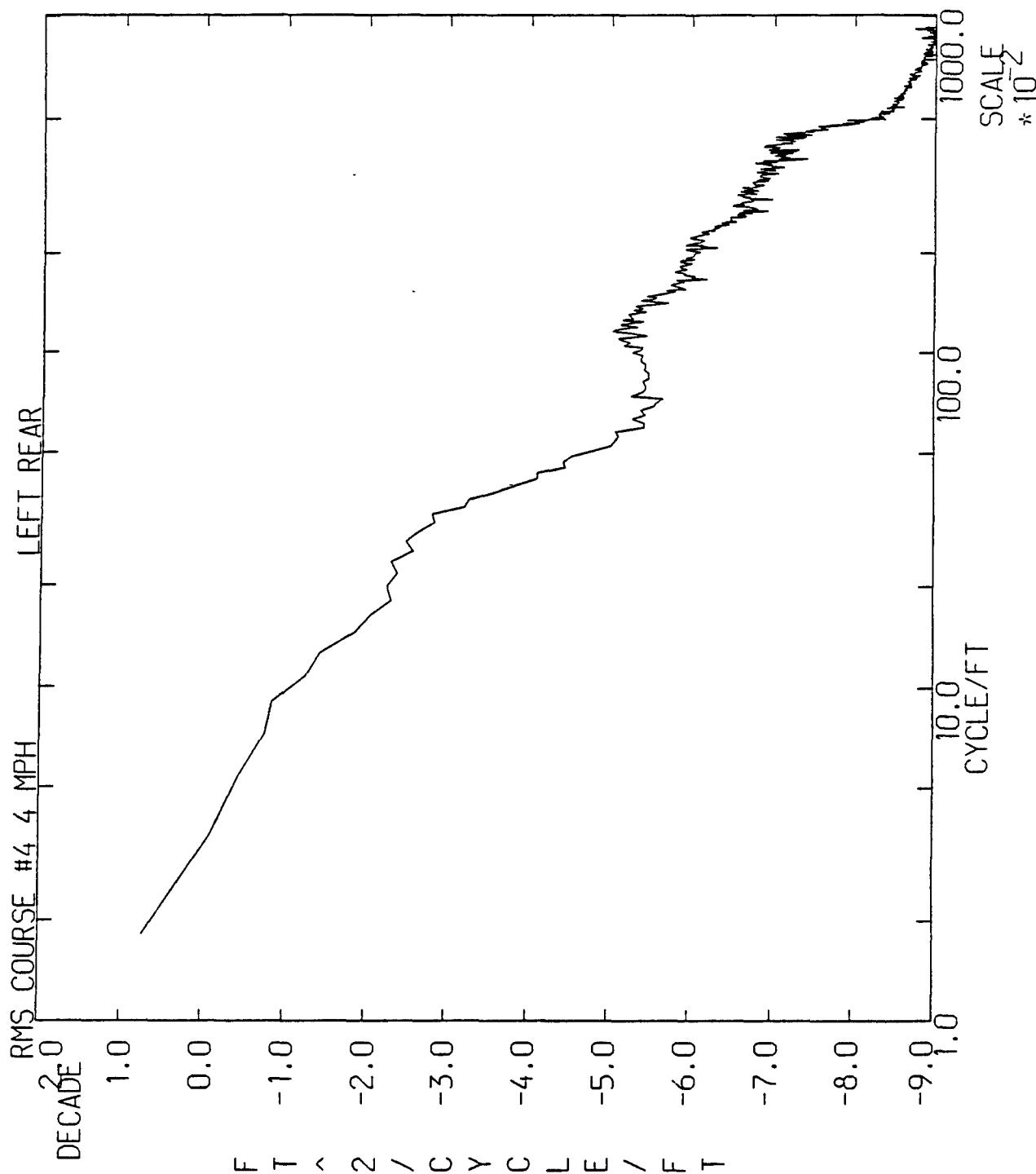
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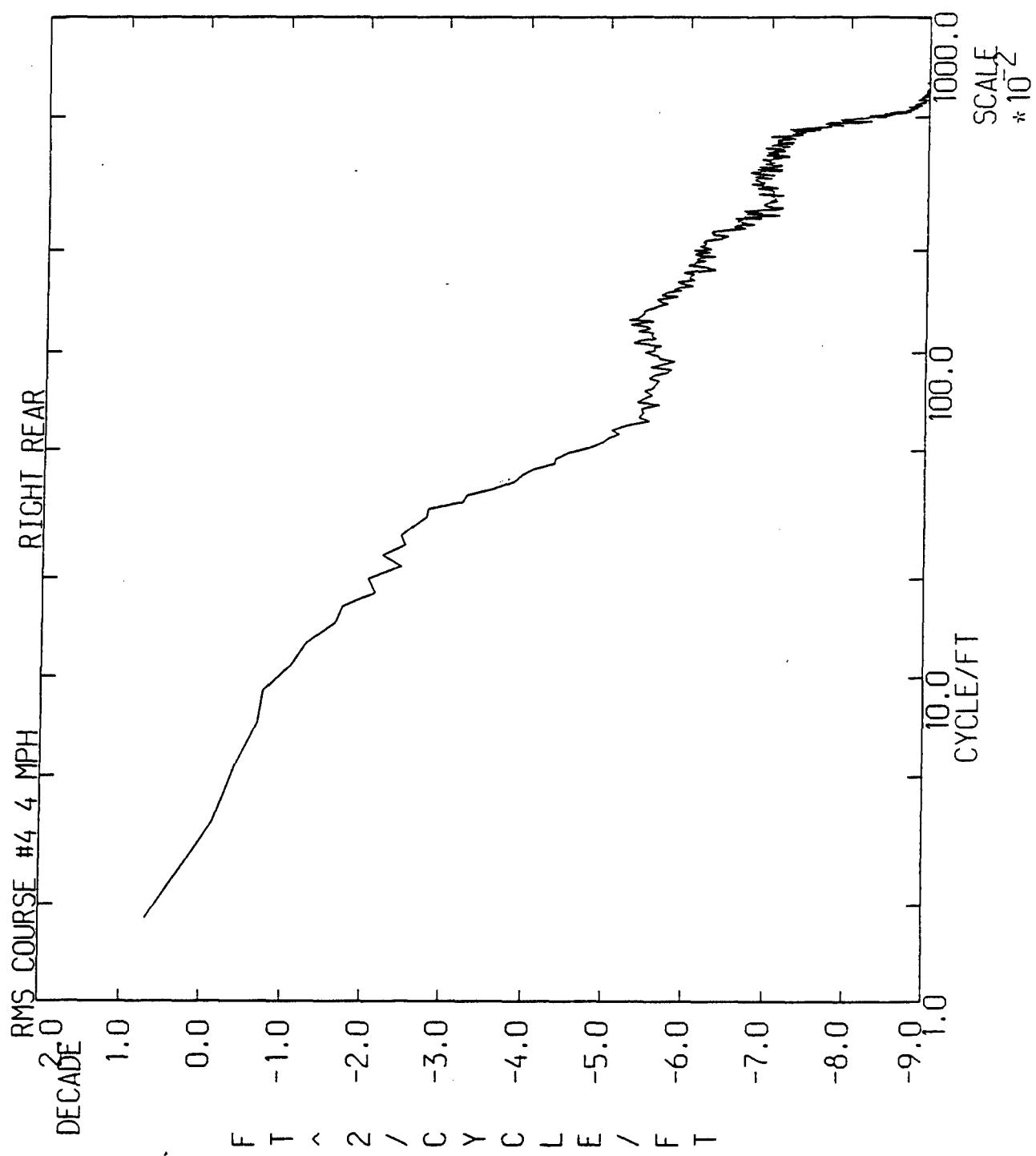


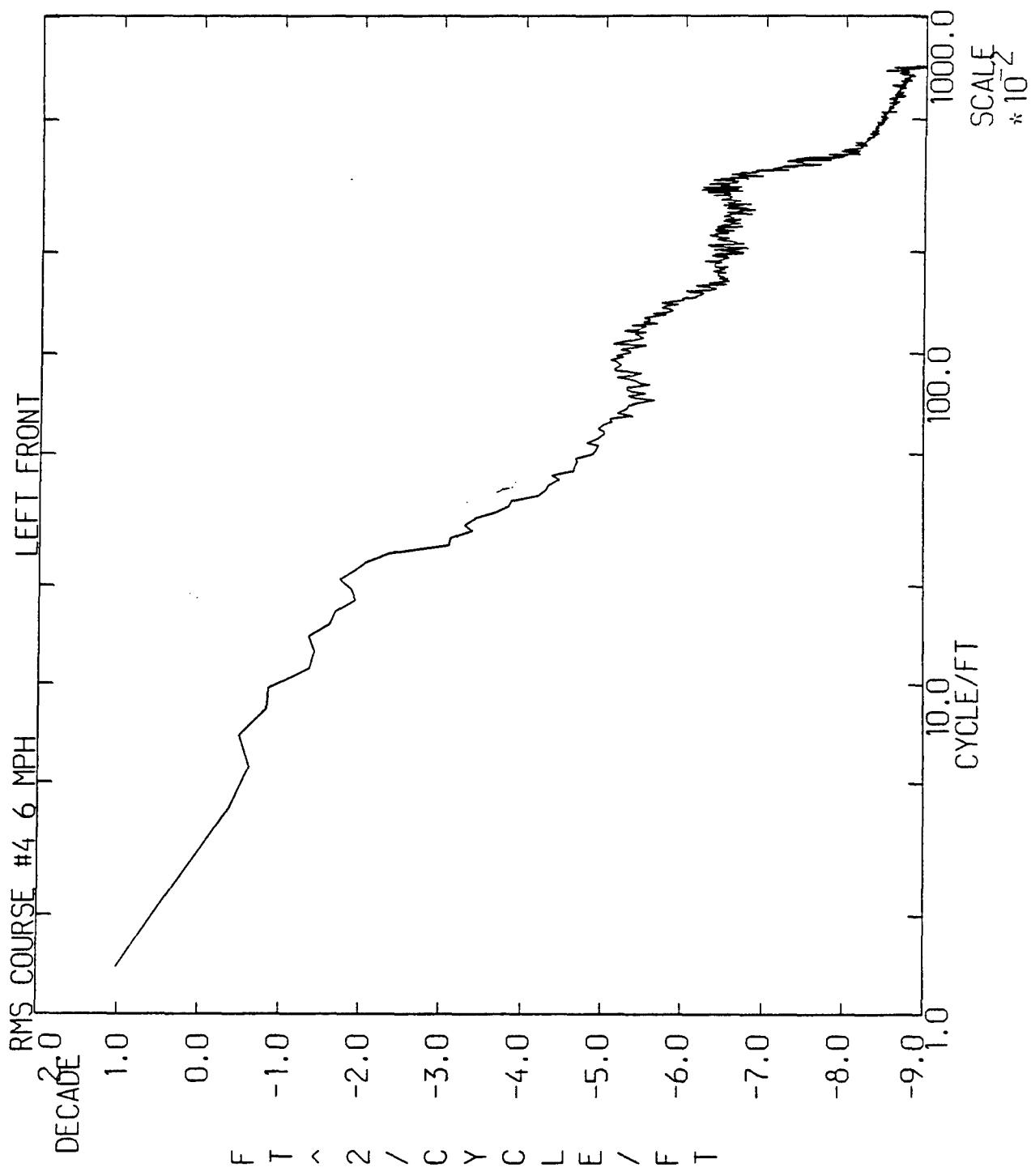


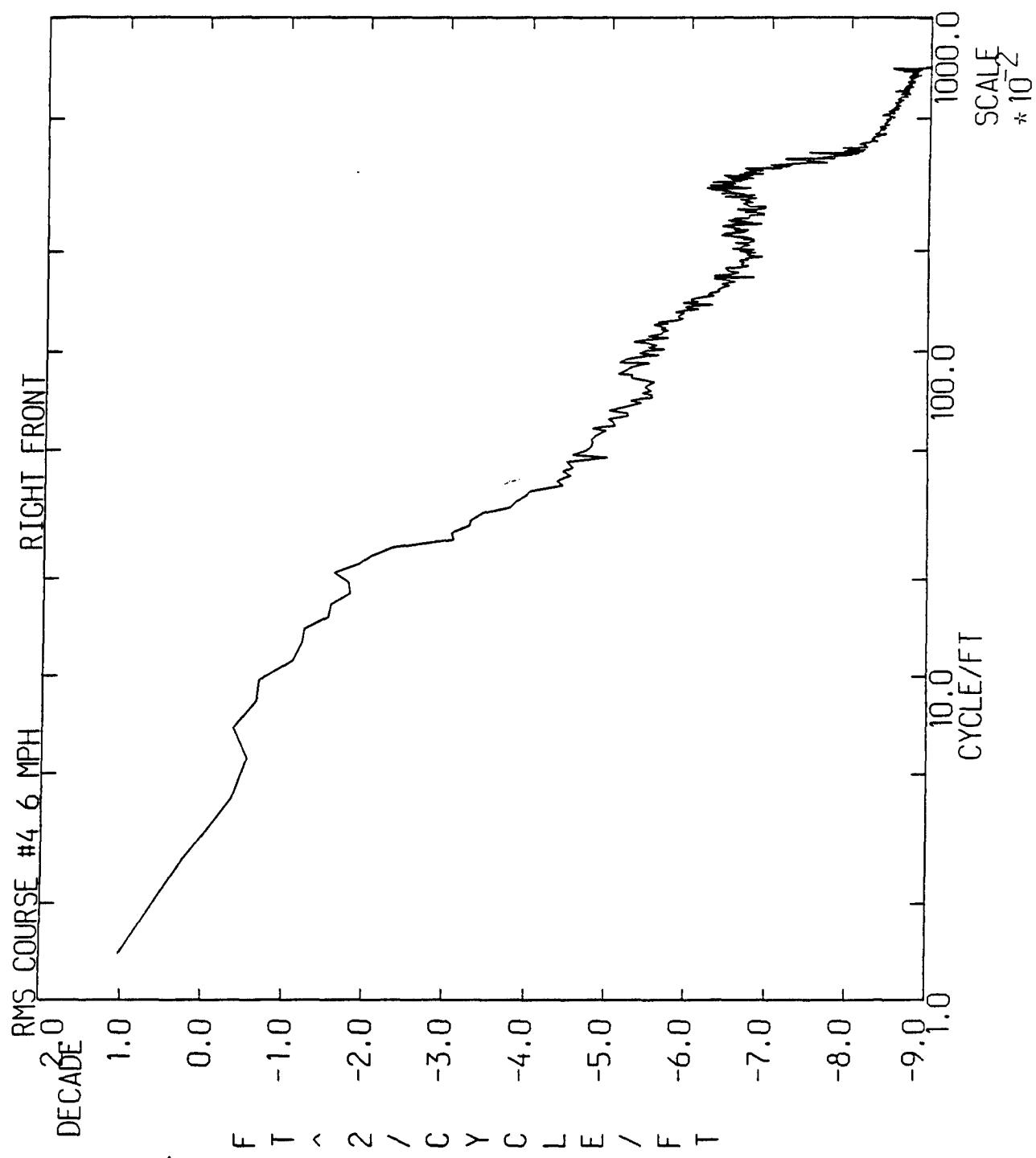
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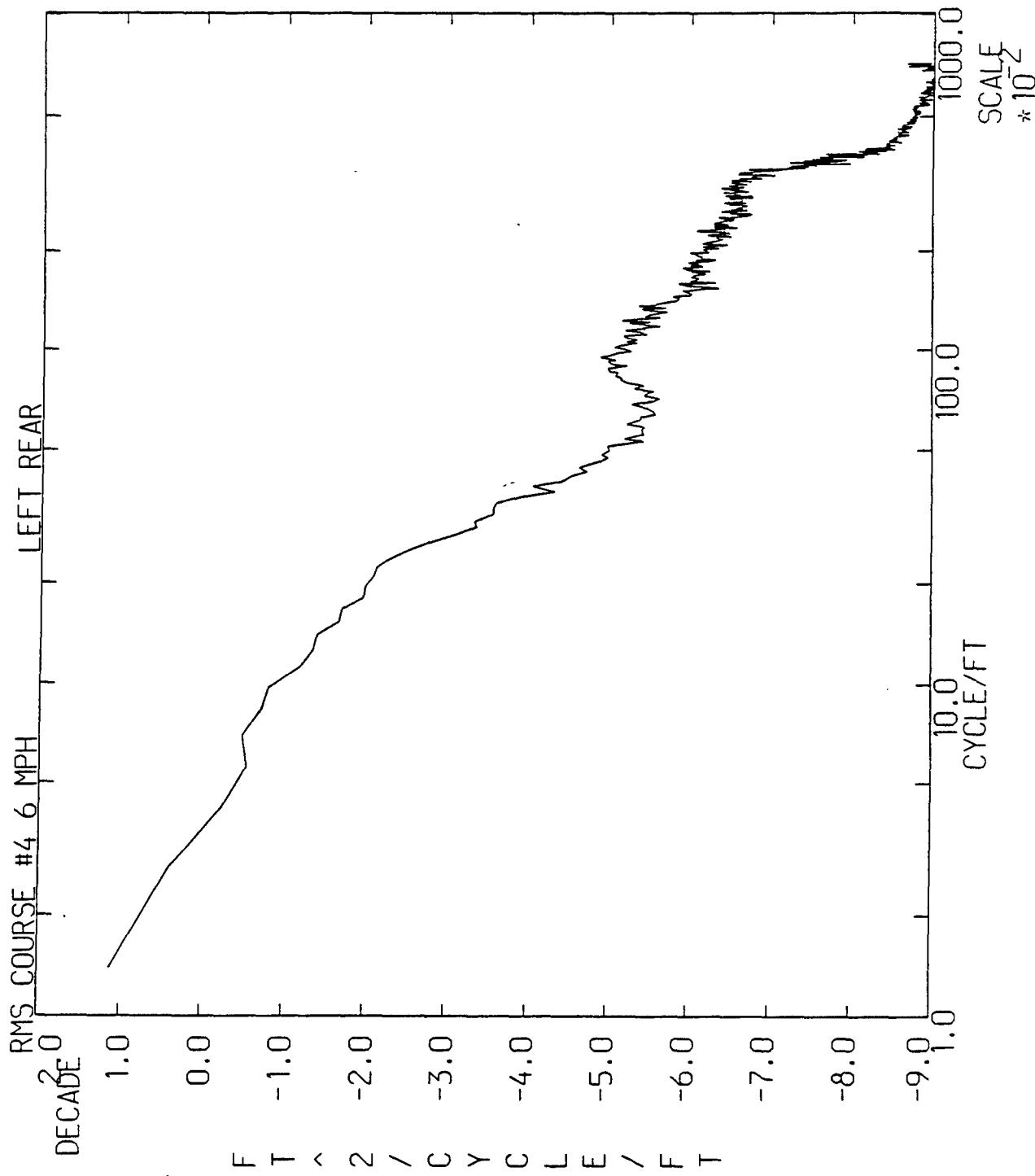
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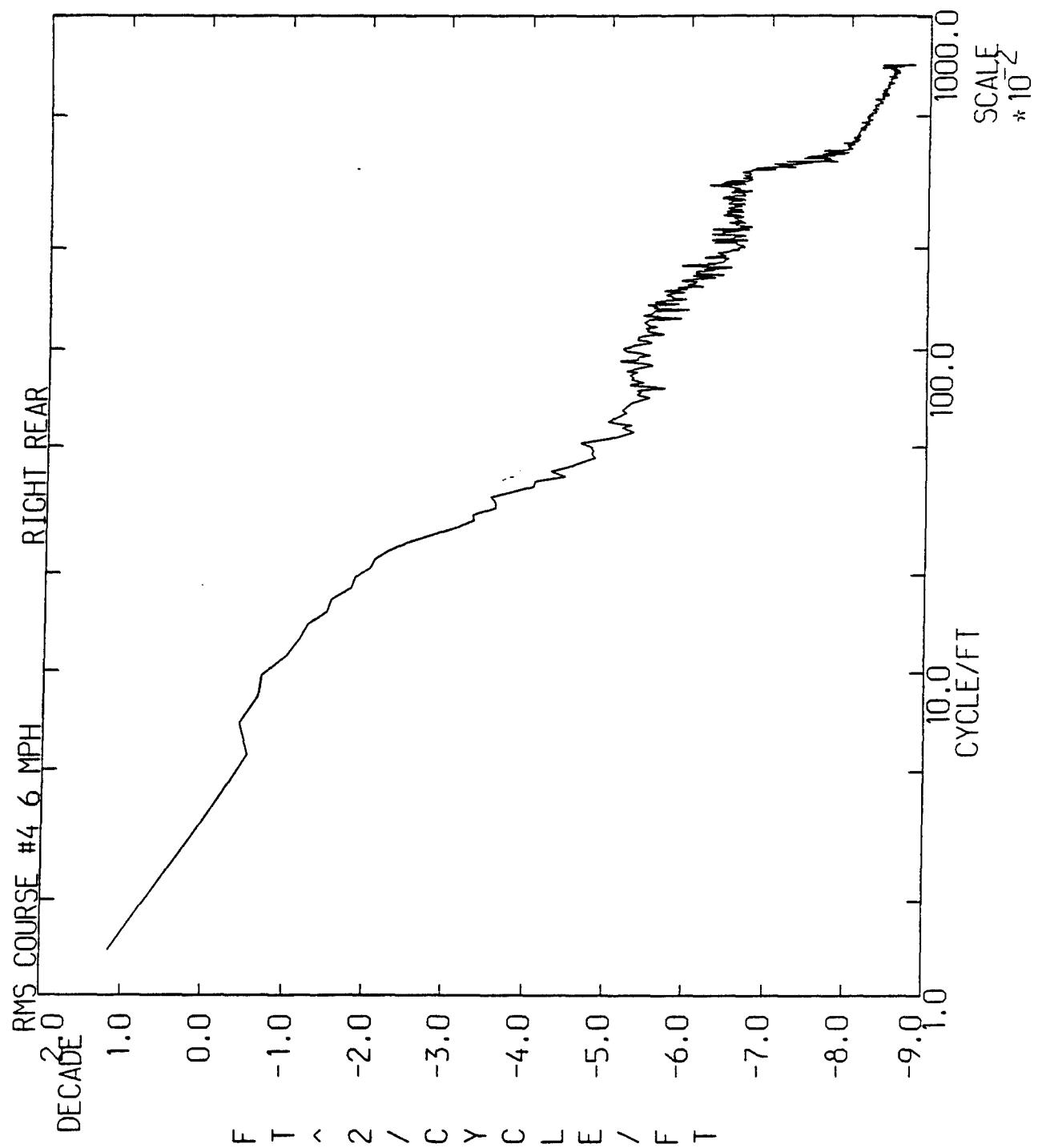




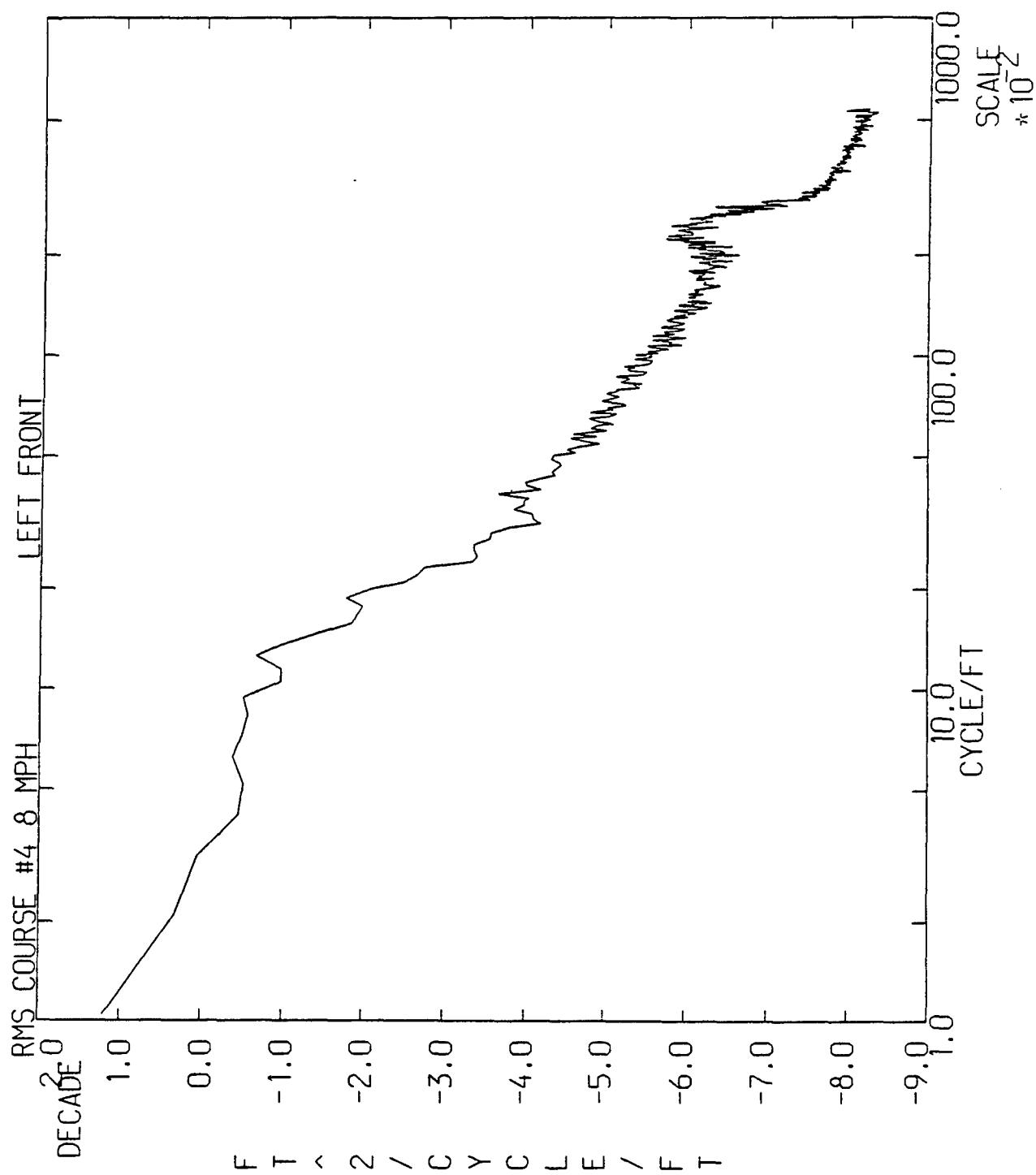


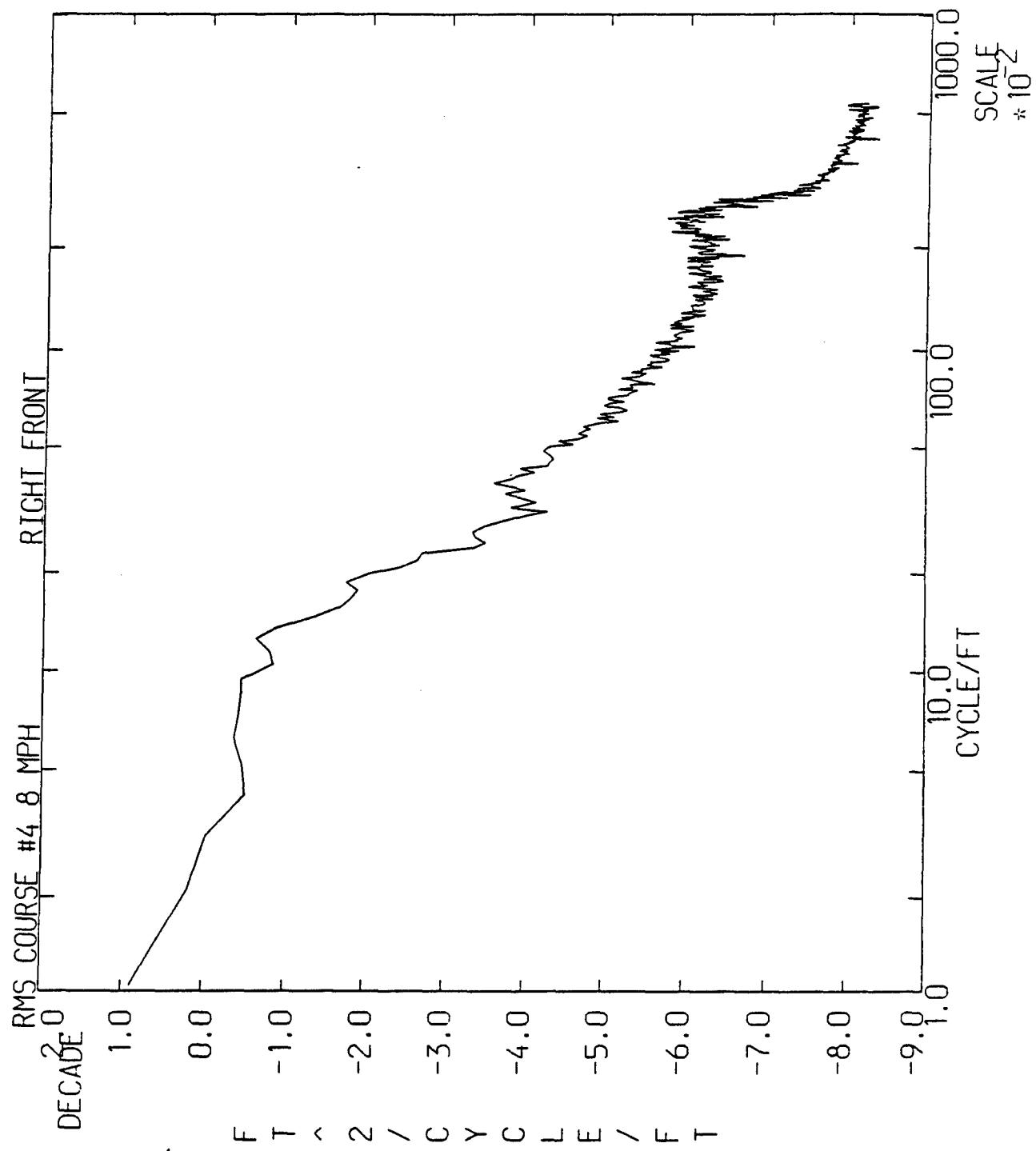
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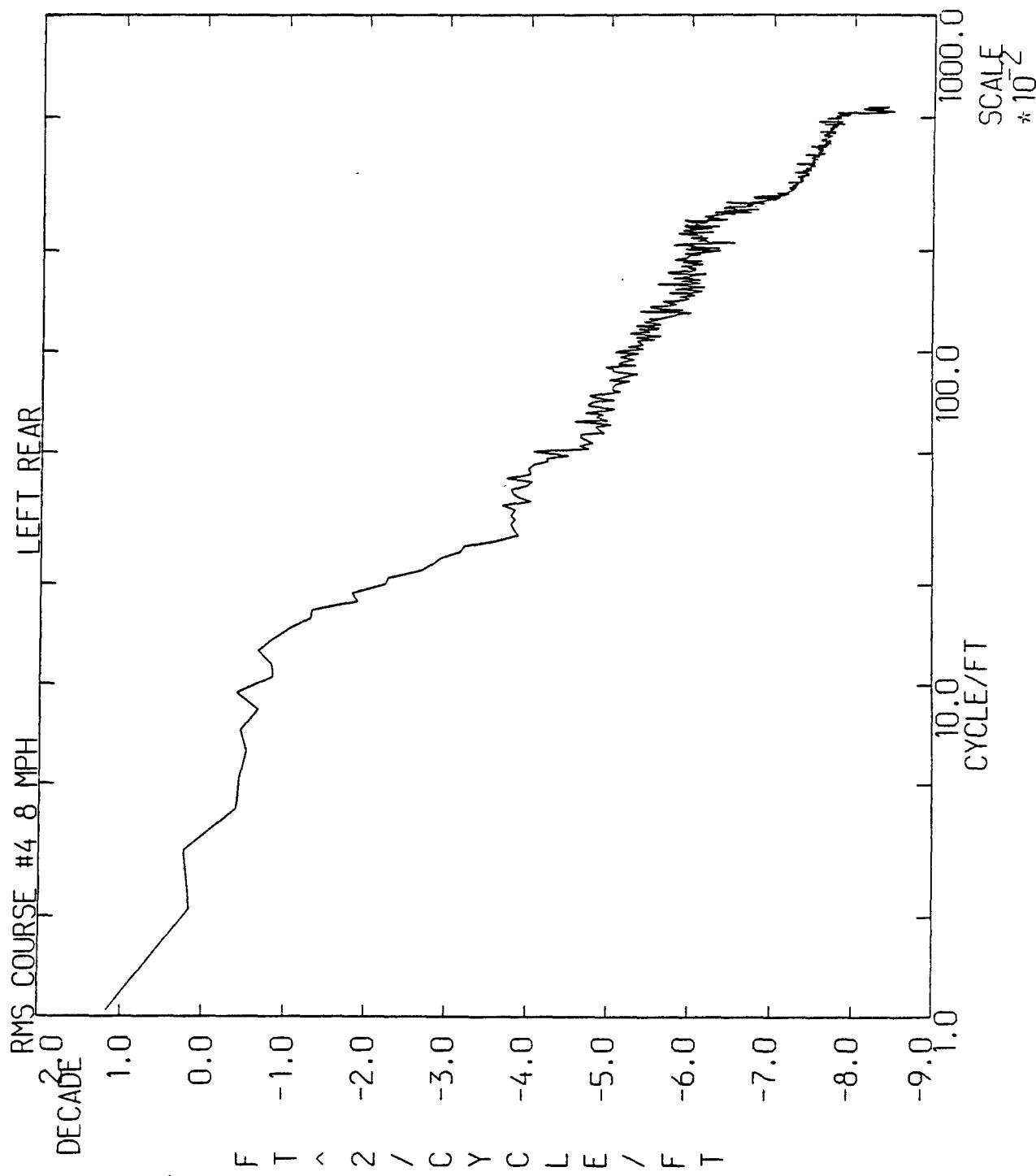


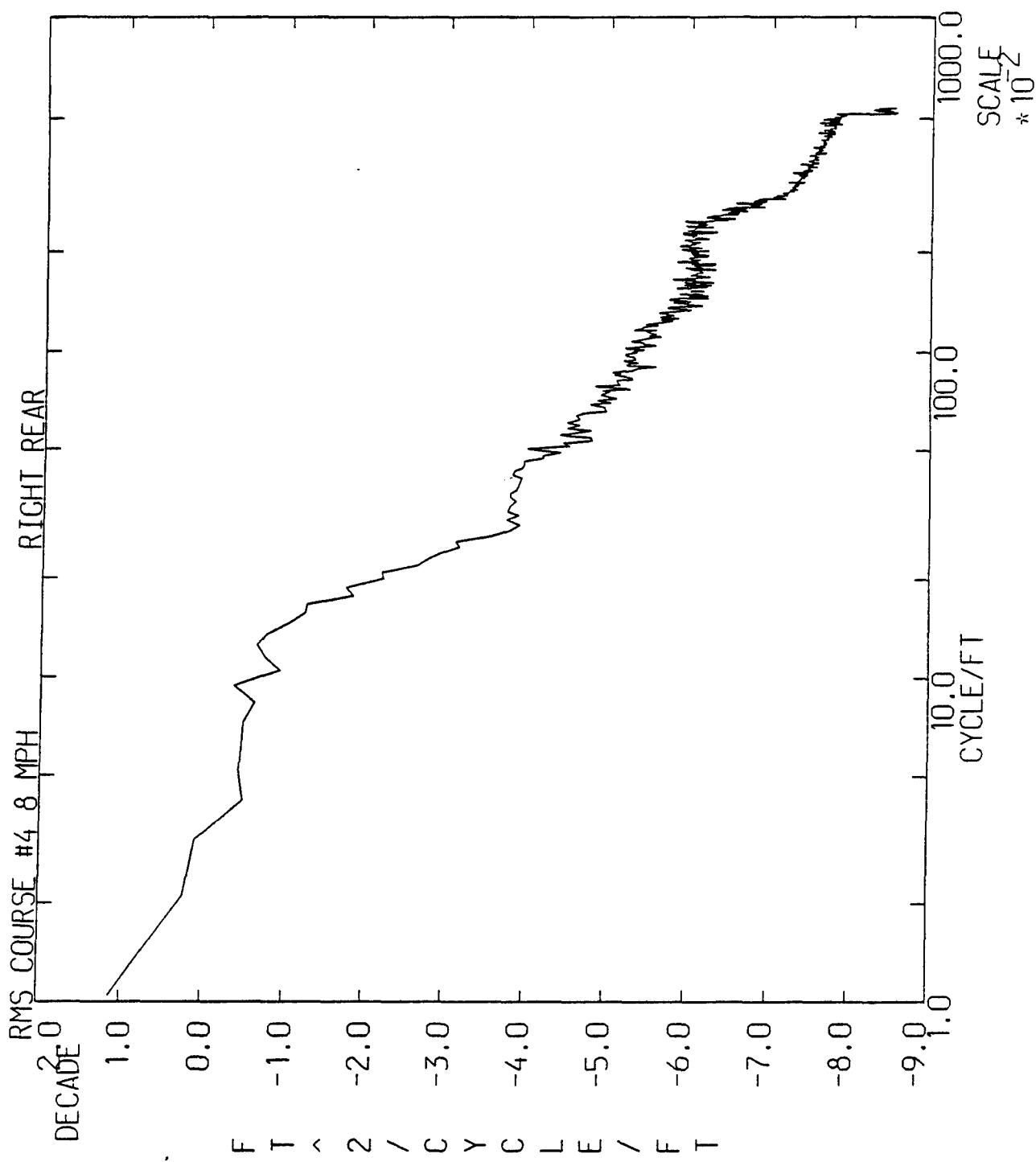
030





032





RMS COURSE #5

WAVE-NUMBER SPECTRA

2, 4, 6 and 8 MPH

Four (4) curves per speed, one for each DFMV tire, as follows

LEFT FRONT
RIGHT FRONT
LEFT REAR
RIGHT REAR

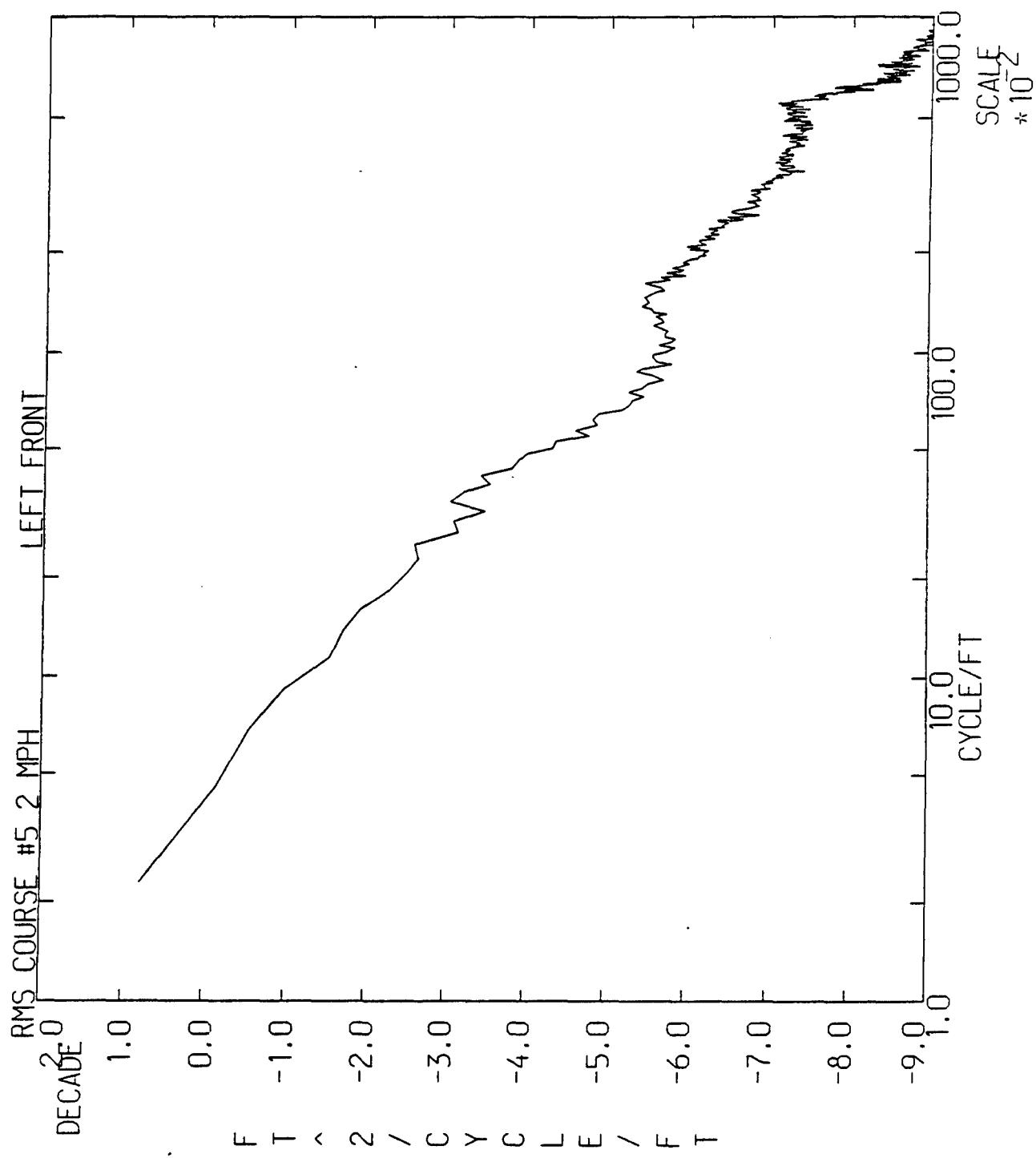
Volume II contains the data for the different DFMV speeds over each YPG course. The data was previously submitted to TACOM in an interim data report, however, the data was not reprocessed with the signal processing considerations discussed in the Volume I report (e.g., in this data, much of the spectral resolution was below the footprint). The wave-number cut-off at the low end of the spectra was limited by the frequency range of the accelerometer, as discussed in the report and shown in the table below. The wave-number cut-off at the high end of the spectrum was limited by the footprint length of the DFMV tire, which was $\approx 1.2 \text{ ft}^{-1}$. These cut-offs were verified through the DFMV front-to-rear coherence plots. Therefore, when comparing plots between different speeds, do not compare the data past these limits. As discussed in the report, the faster speed runs produced the best results at the lower wave numbers.

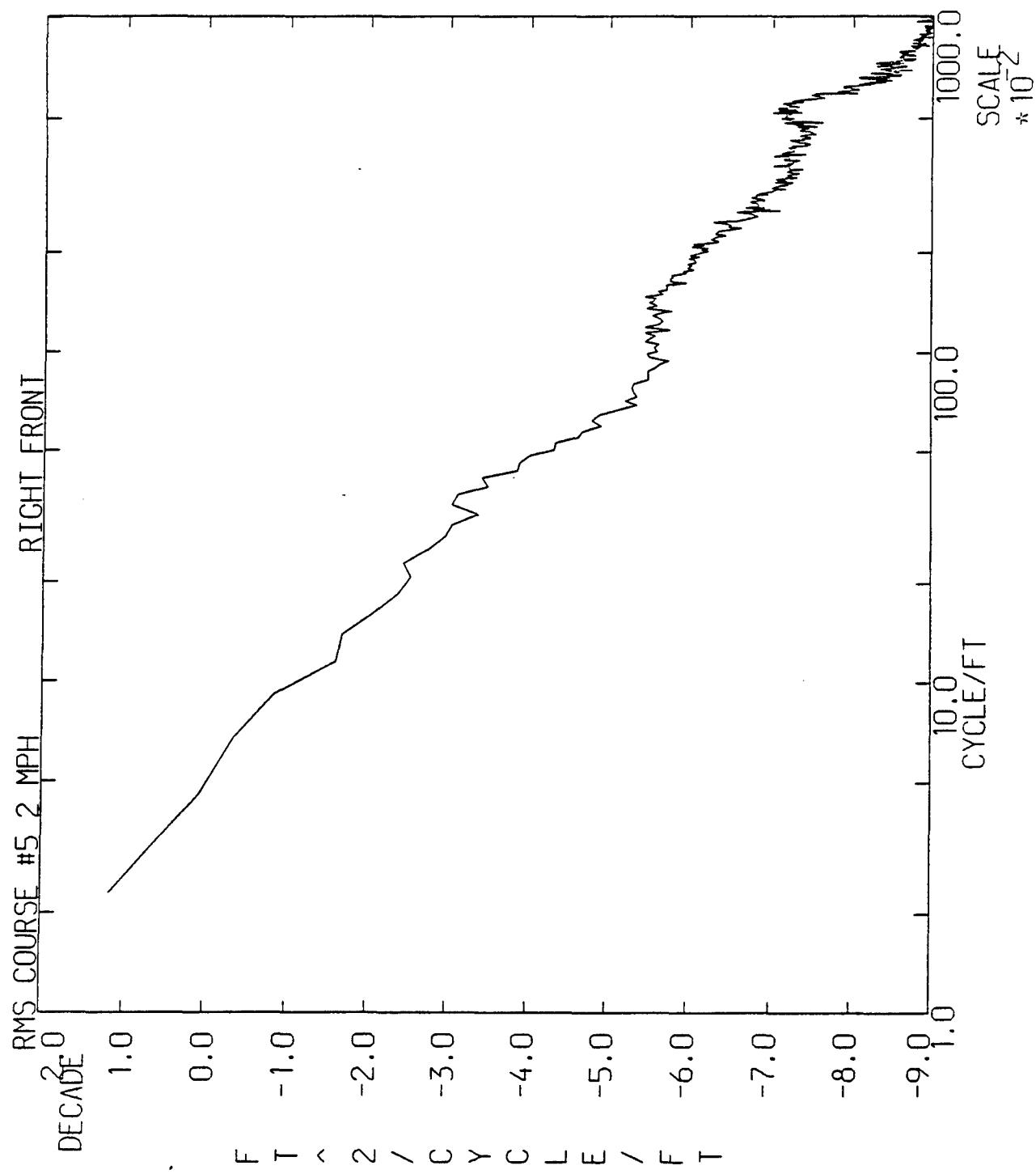
Table 1. DFMV Actual Versus Predicted Wavelength Limits

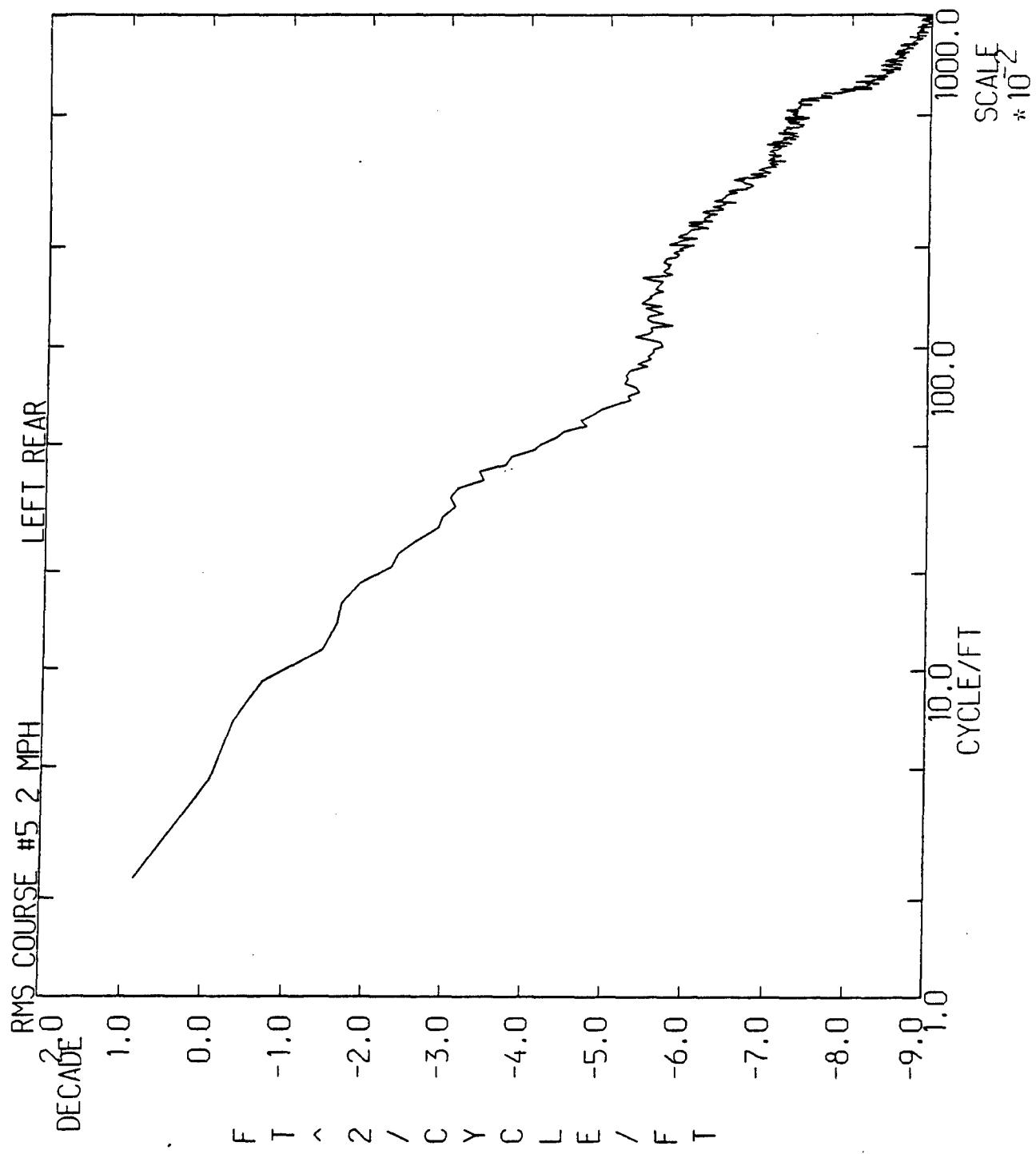
DFMV Speed MPH	Expected Wavelength Resolution*	Actual Wavelength Resolution**
2	60	15
4	120	30
6	180	45
8	240	60
10	300	75

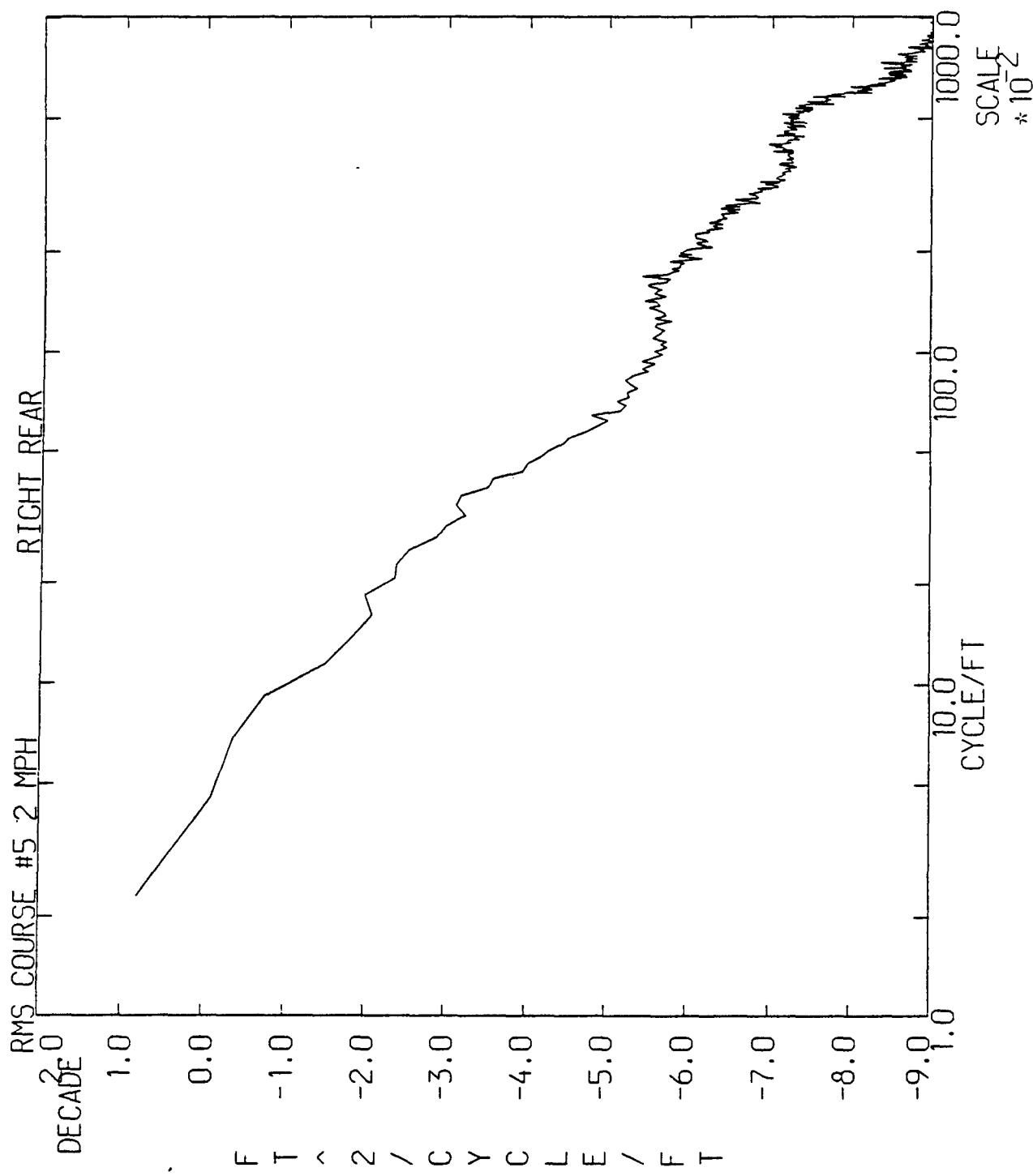
* Based on the advertised low-end frequency range for the accelerometer used

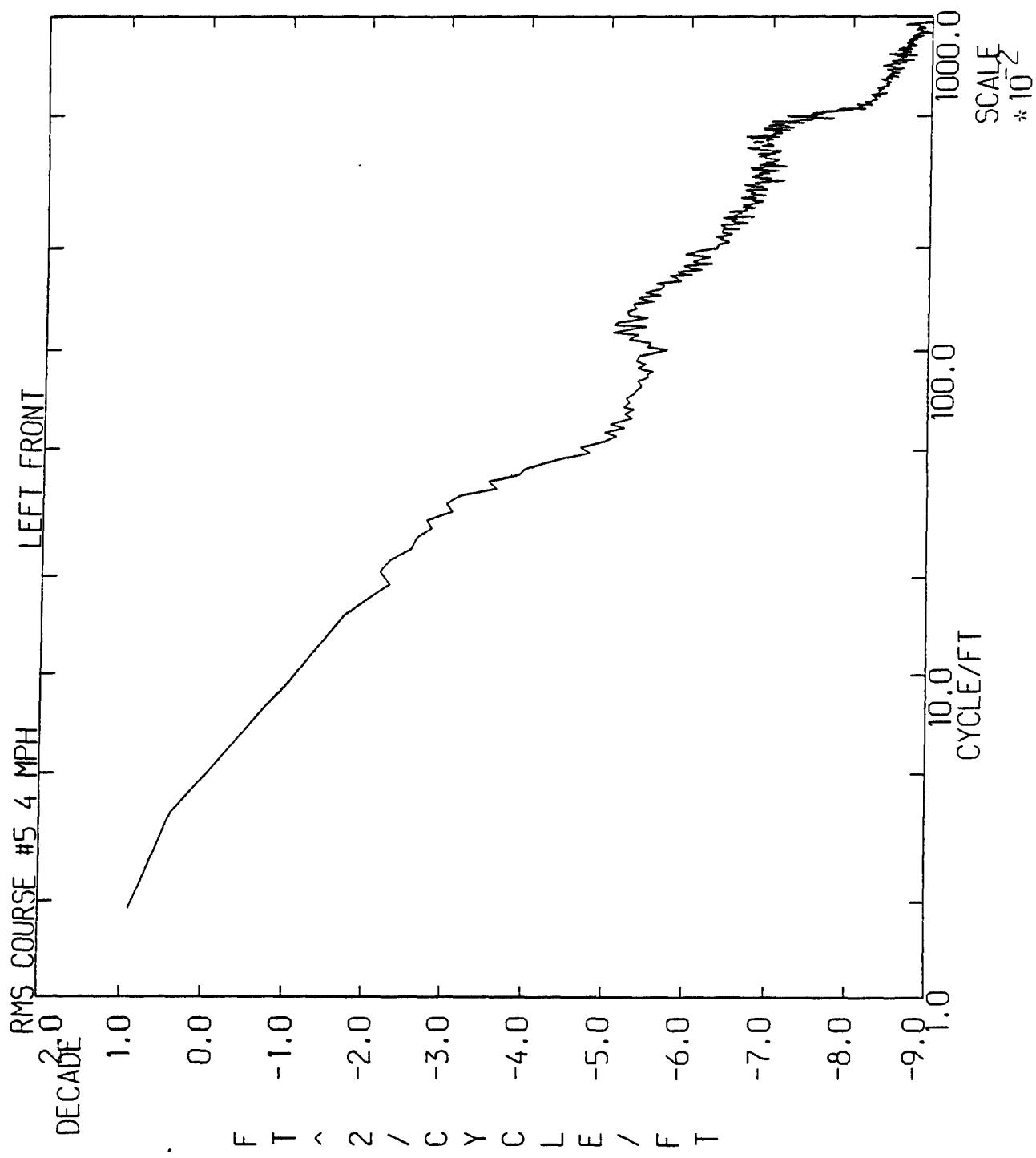
** Based on actual low-end frequency range for the accelerometer used

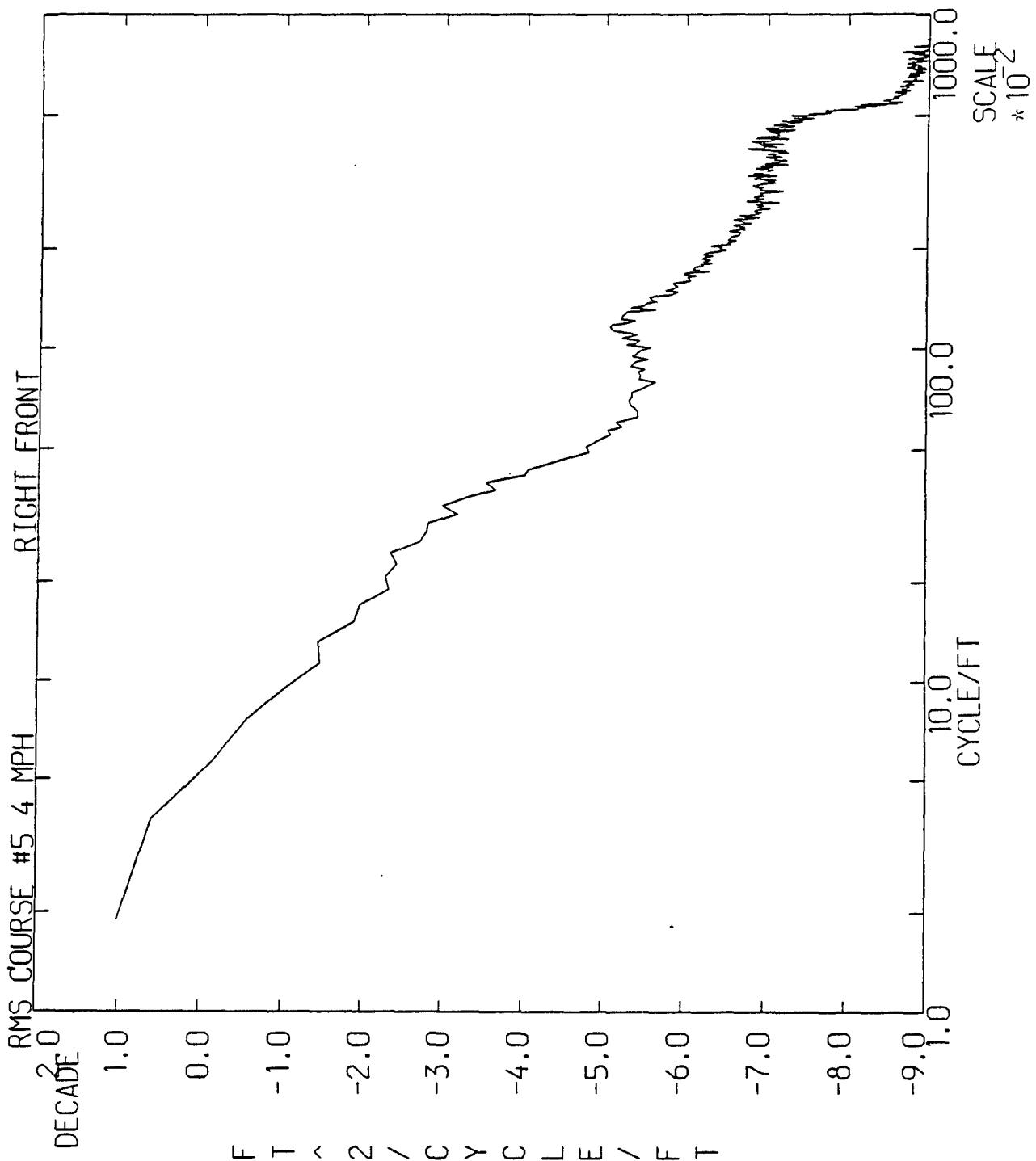




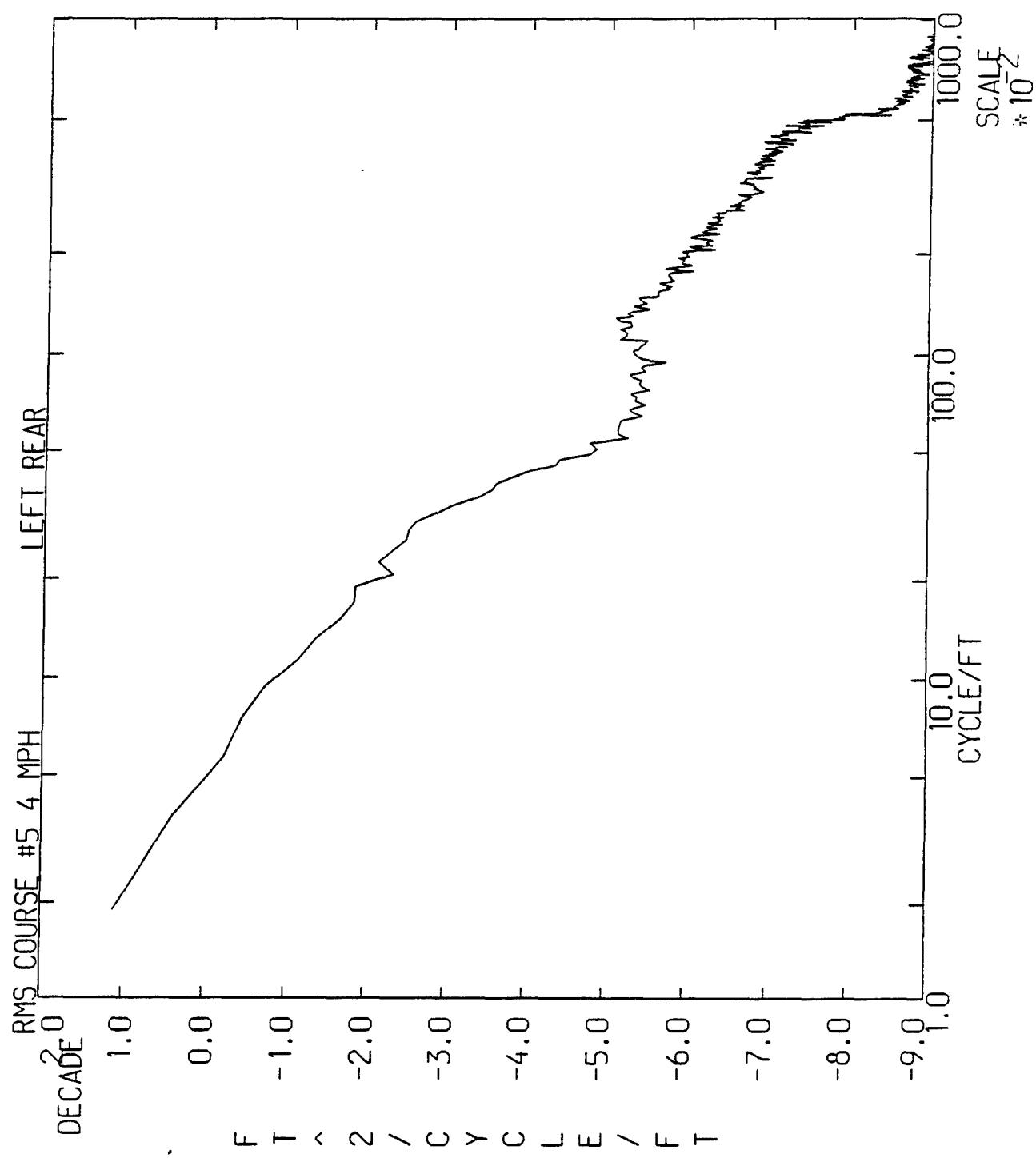


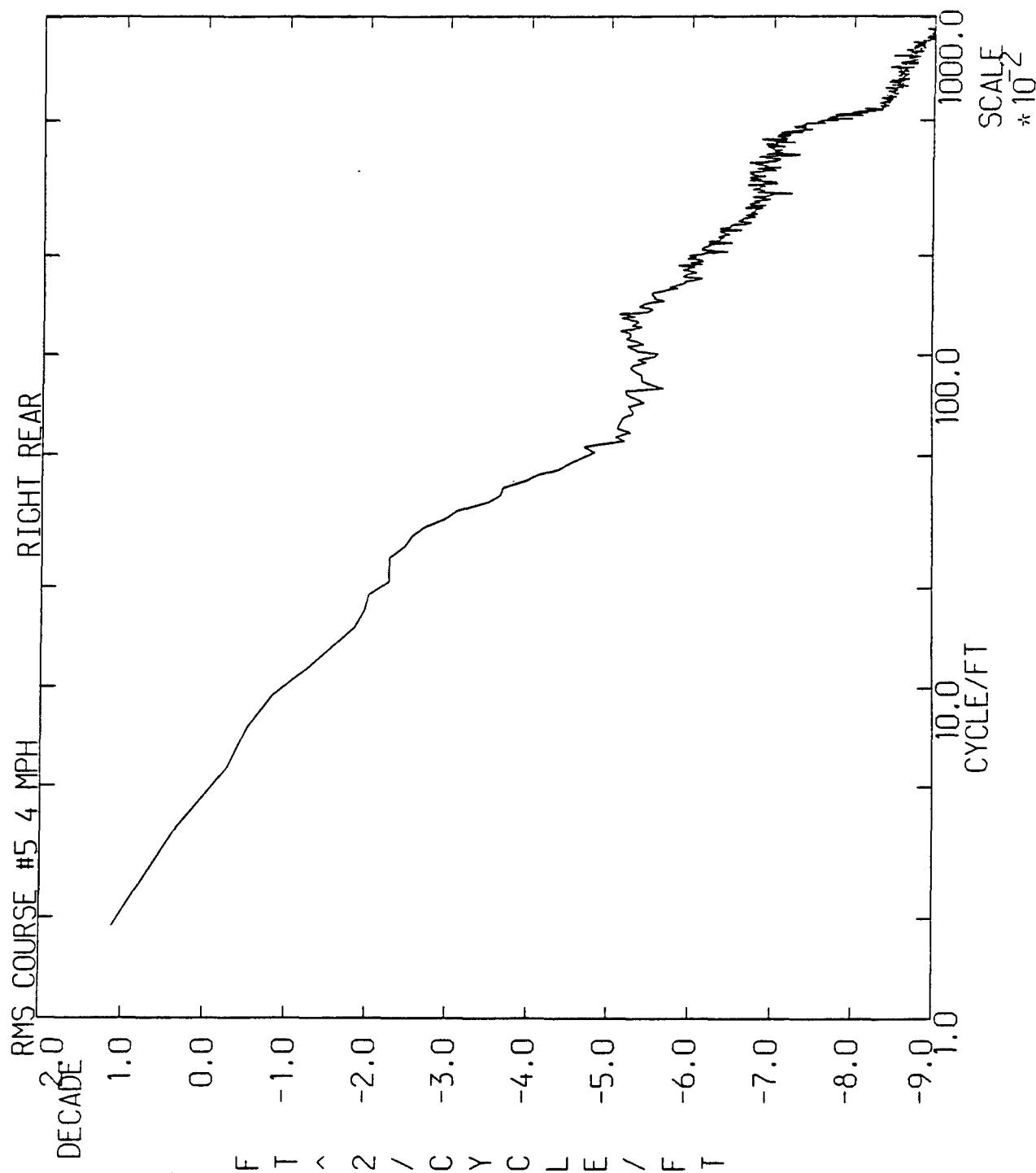


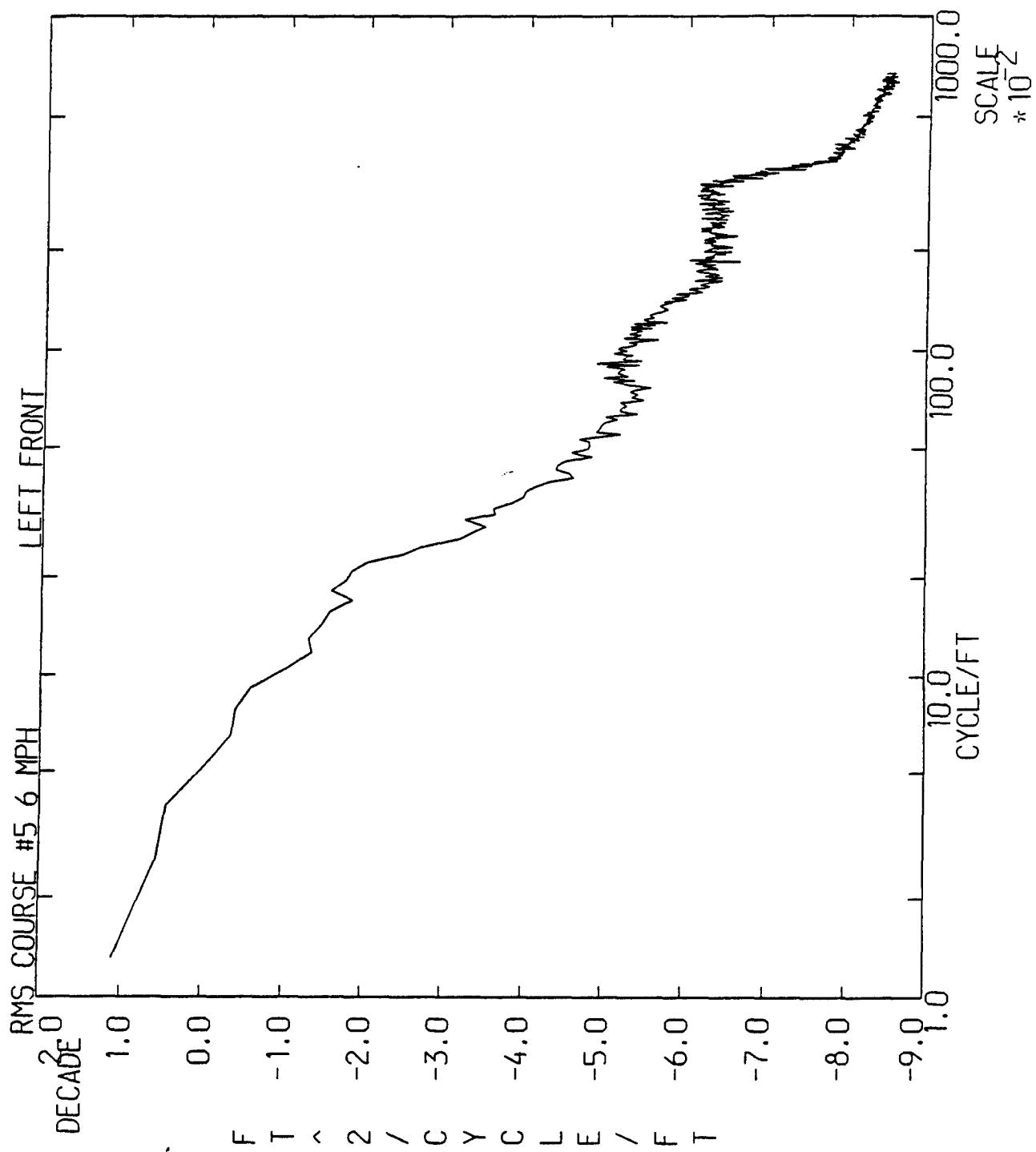


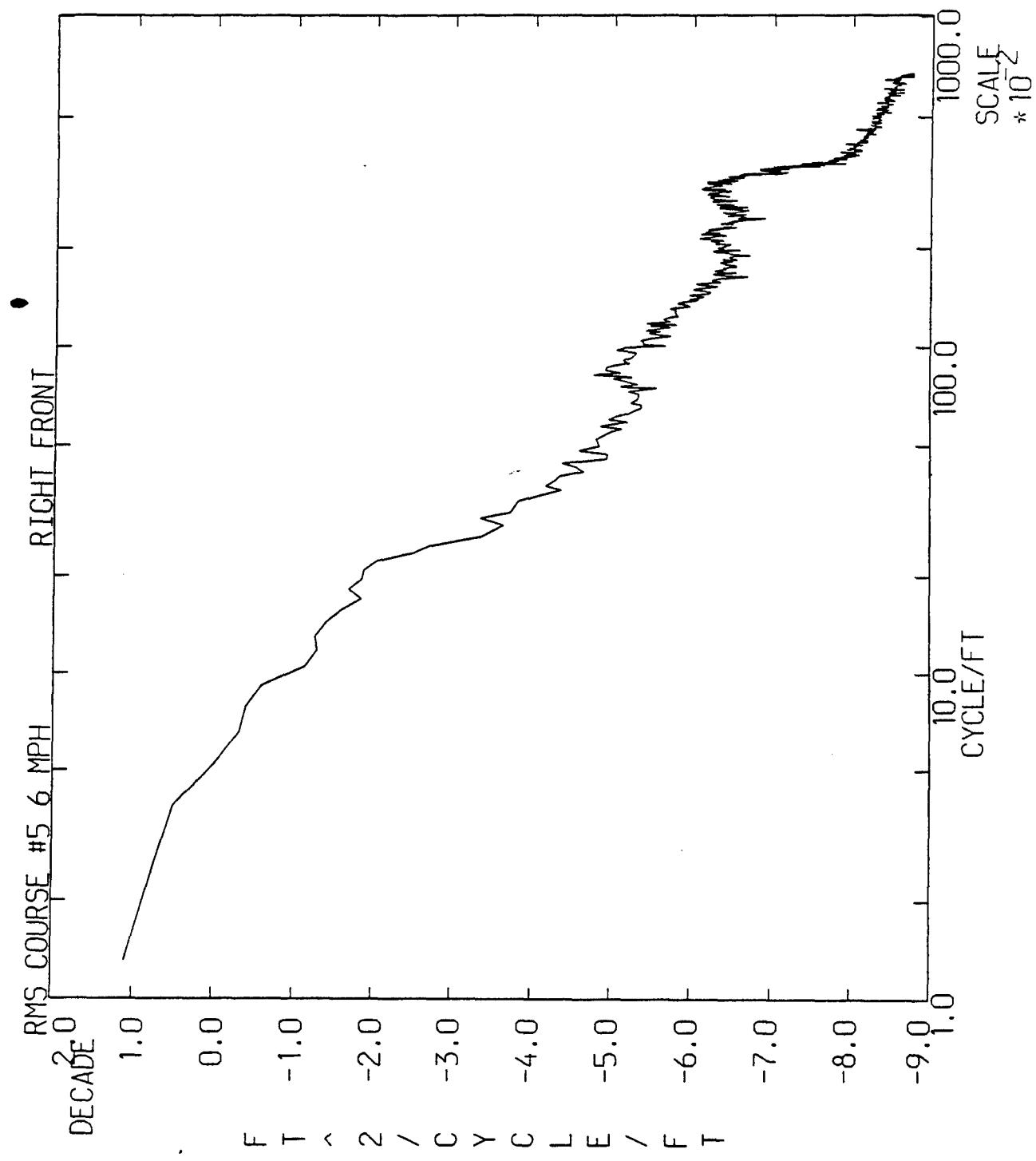


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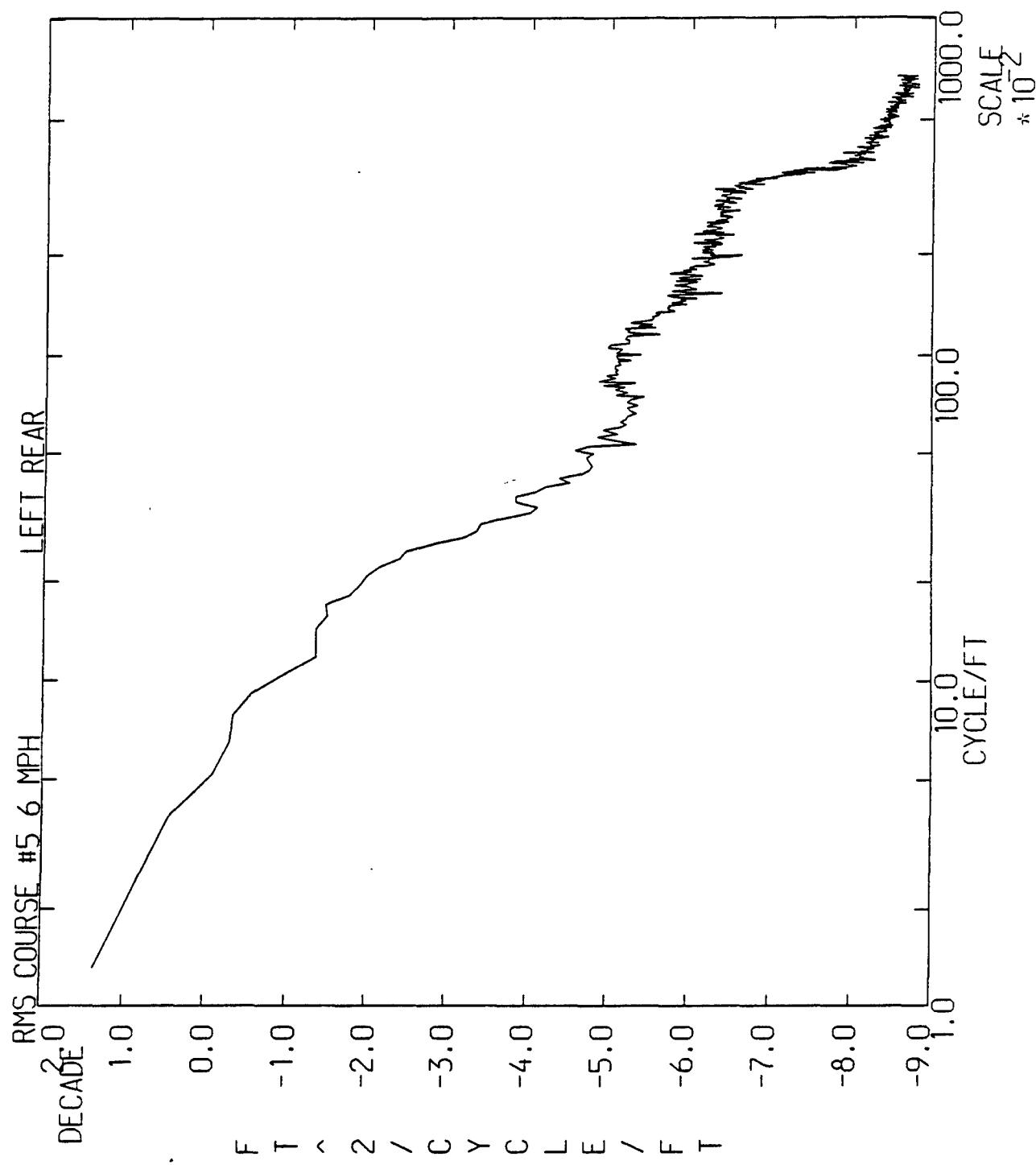


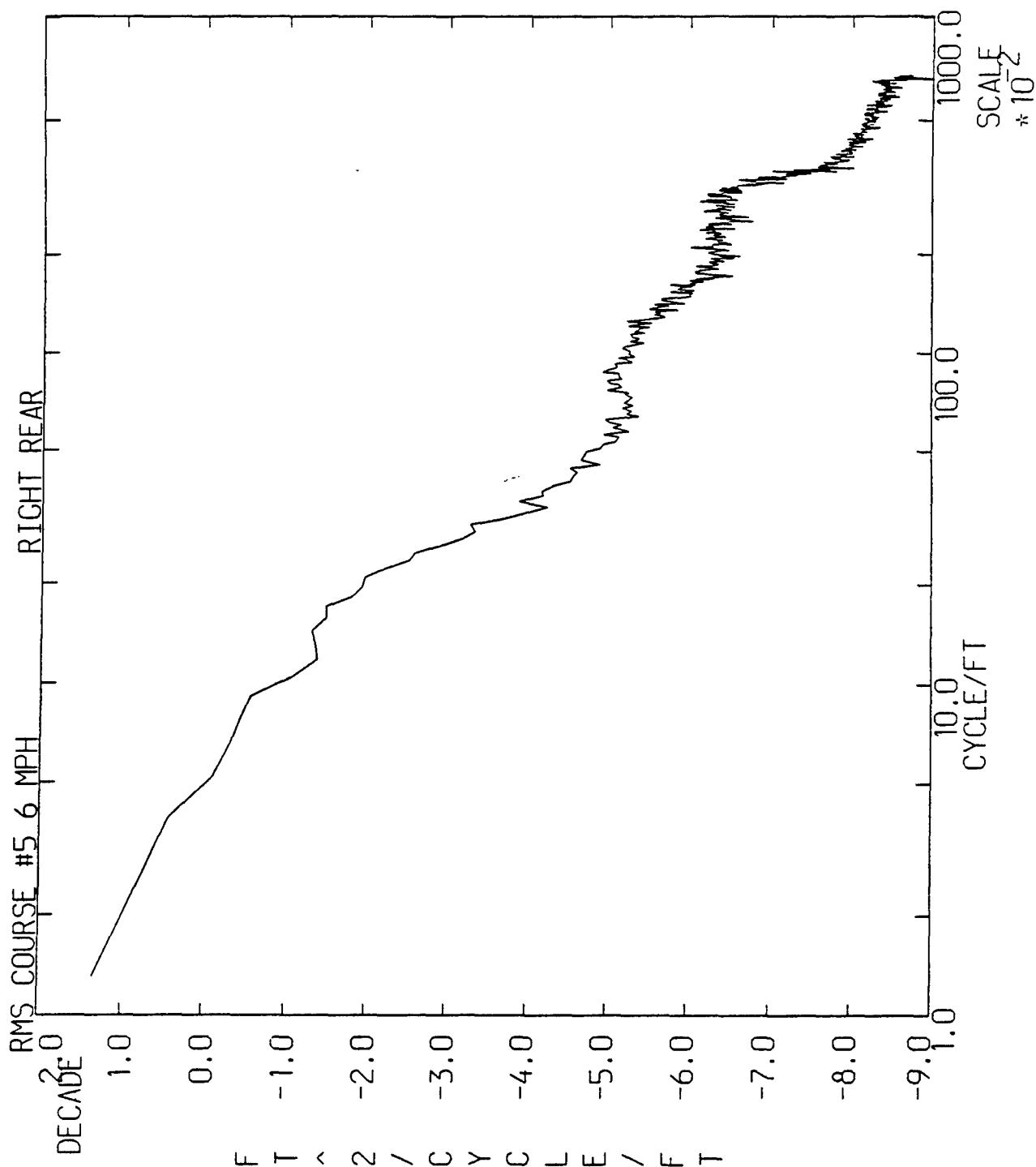


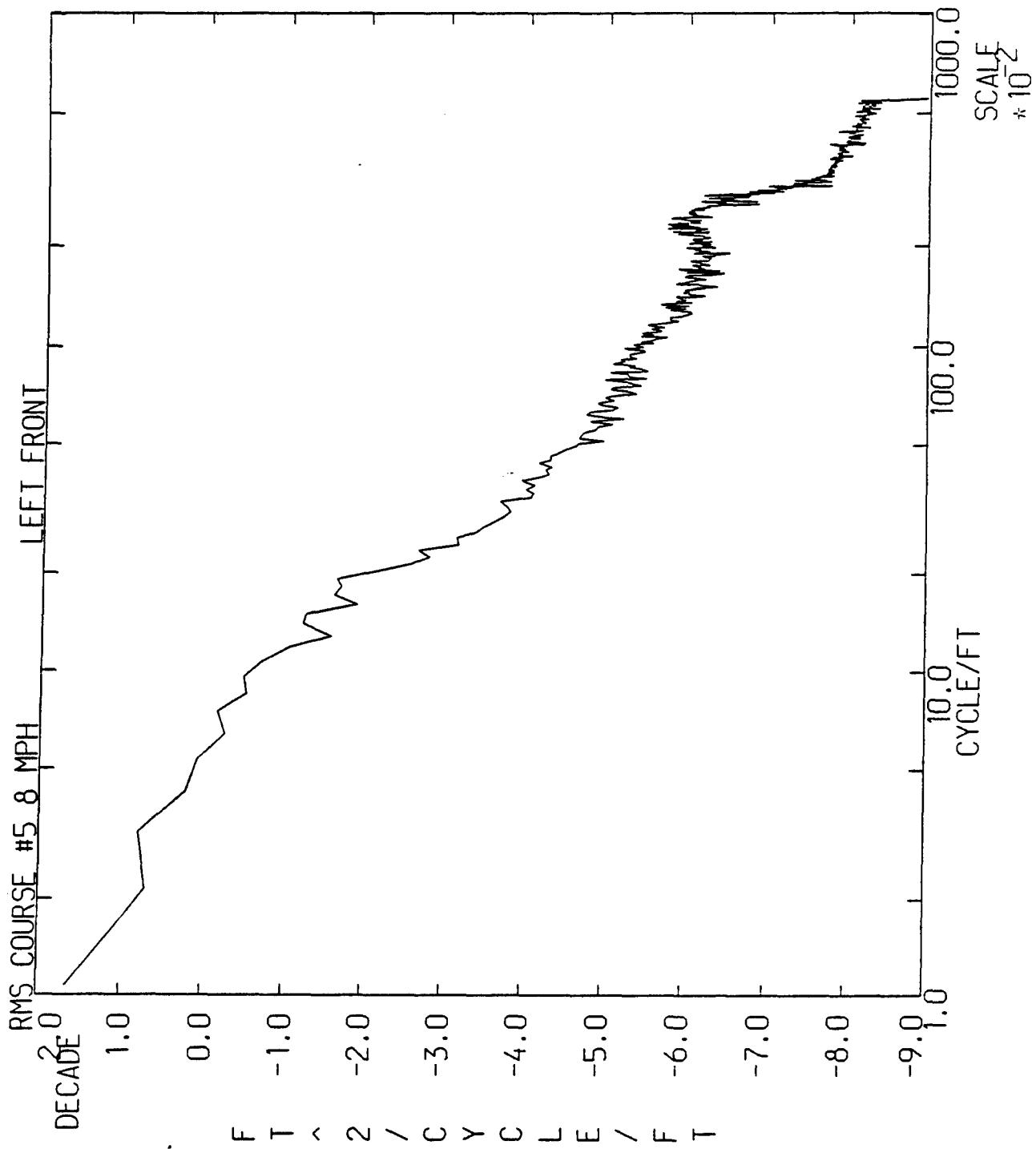




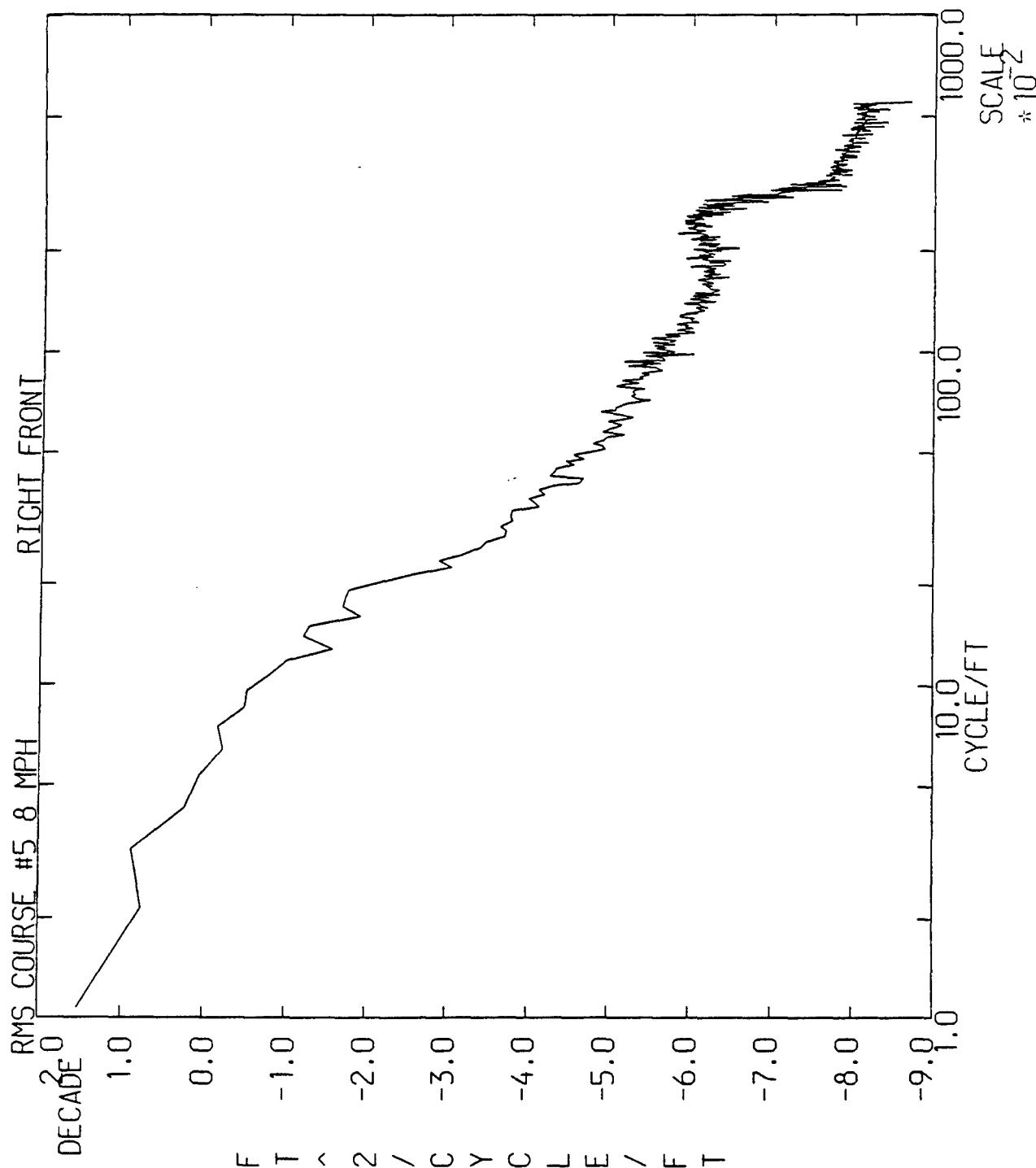
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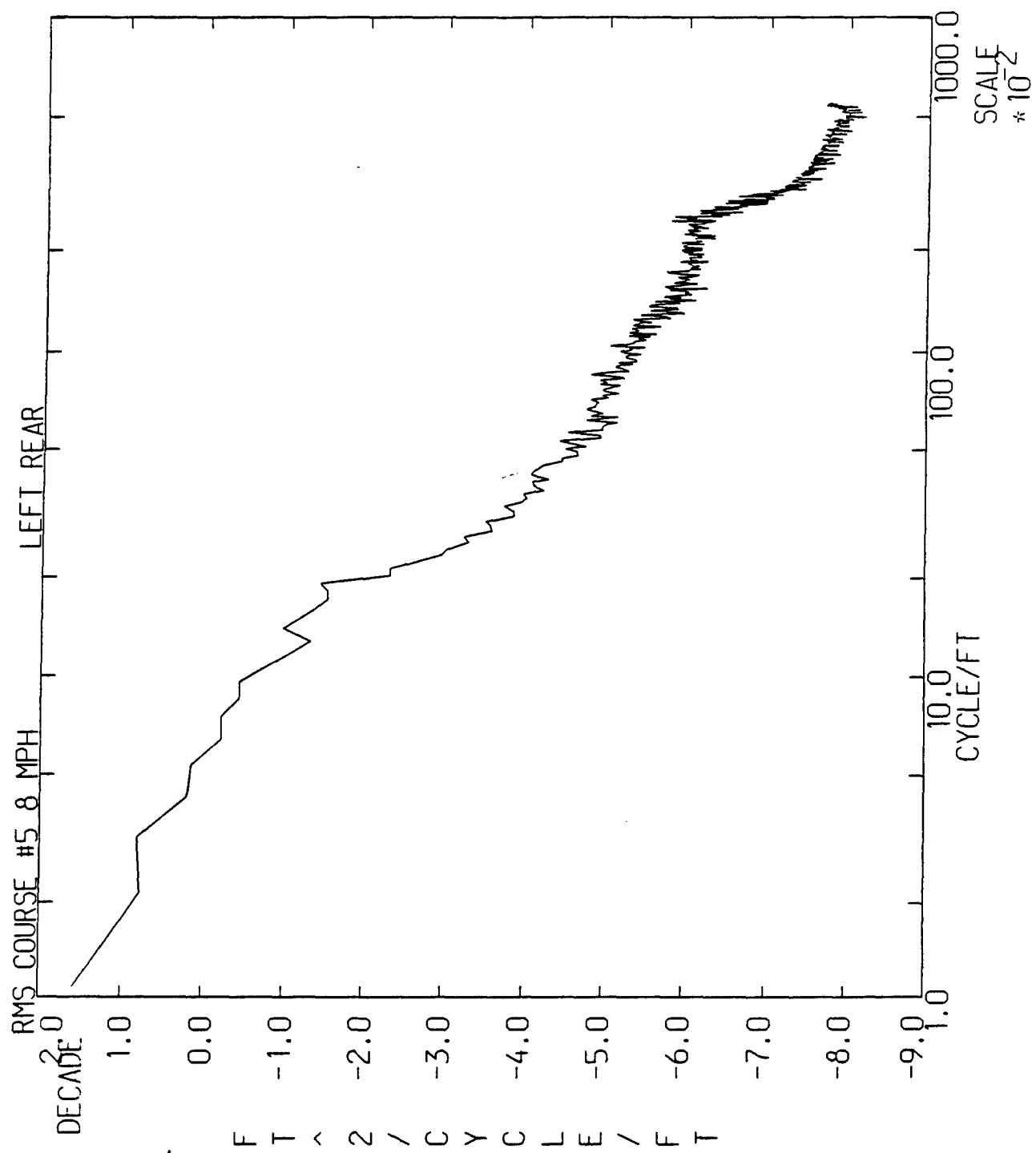




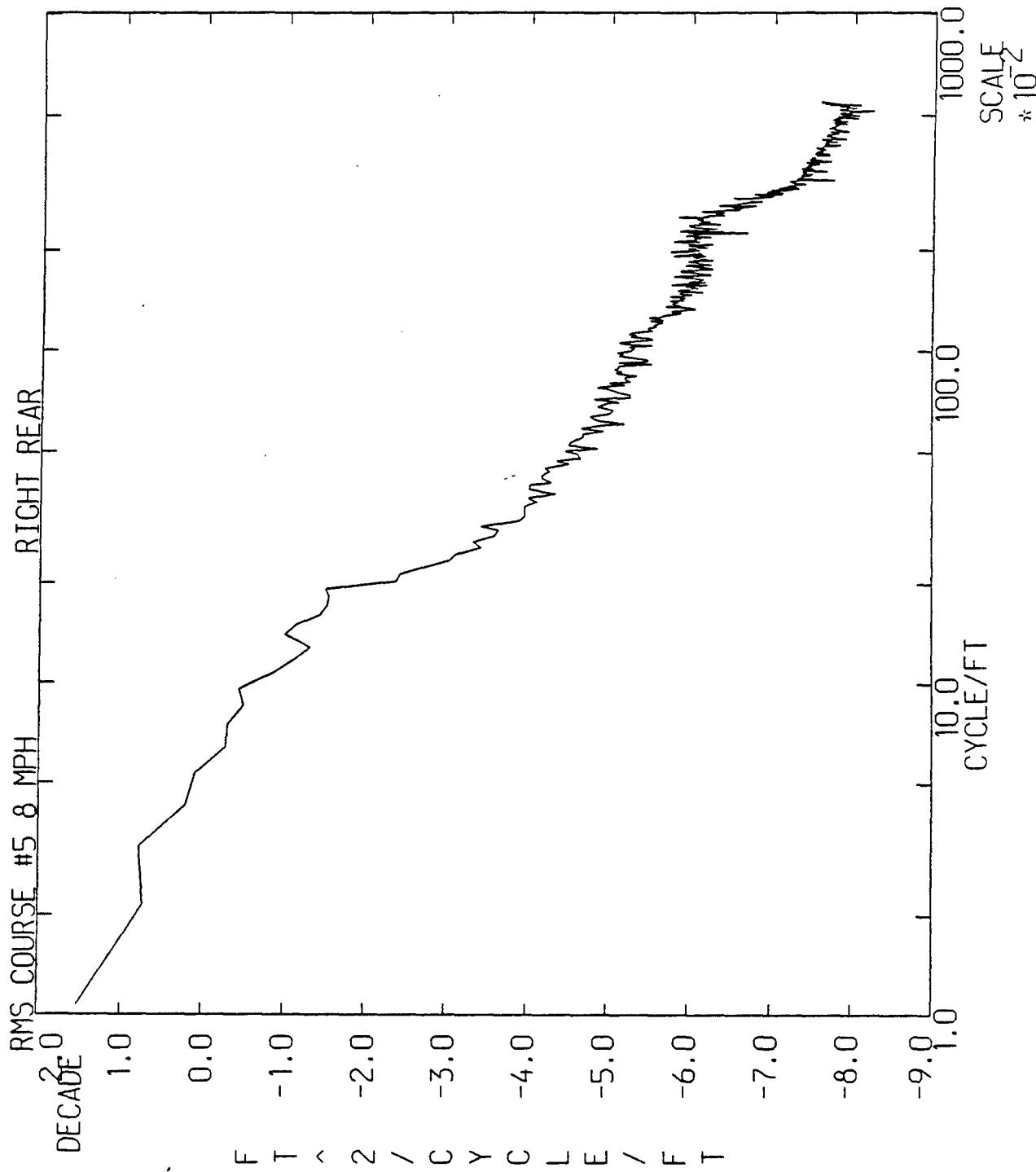


043





050



051

RMS COURSE #2
(Negative Bump or Discrete Event Course)

WAVE-NUMBER SPECTRA

2, 4, 6, 8 and 10 MPH

Four (4) curves per speed, one for each DFMV tire, as follows

**LEFT FRONT
RIGHT FRONT
LEFT REAR
RIGHT REAR**

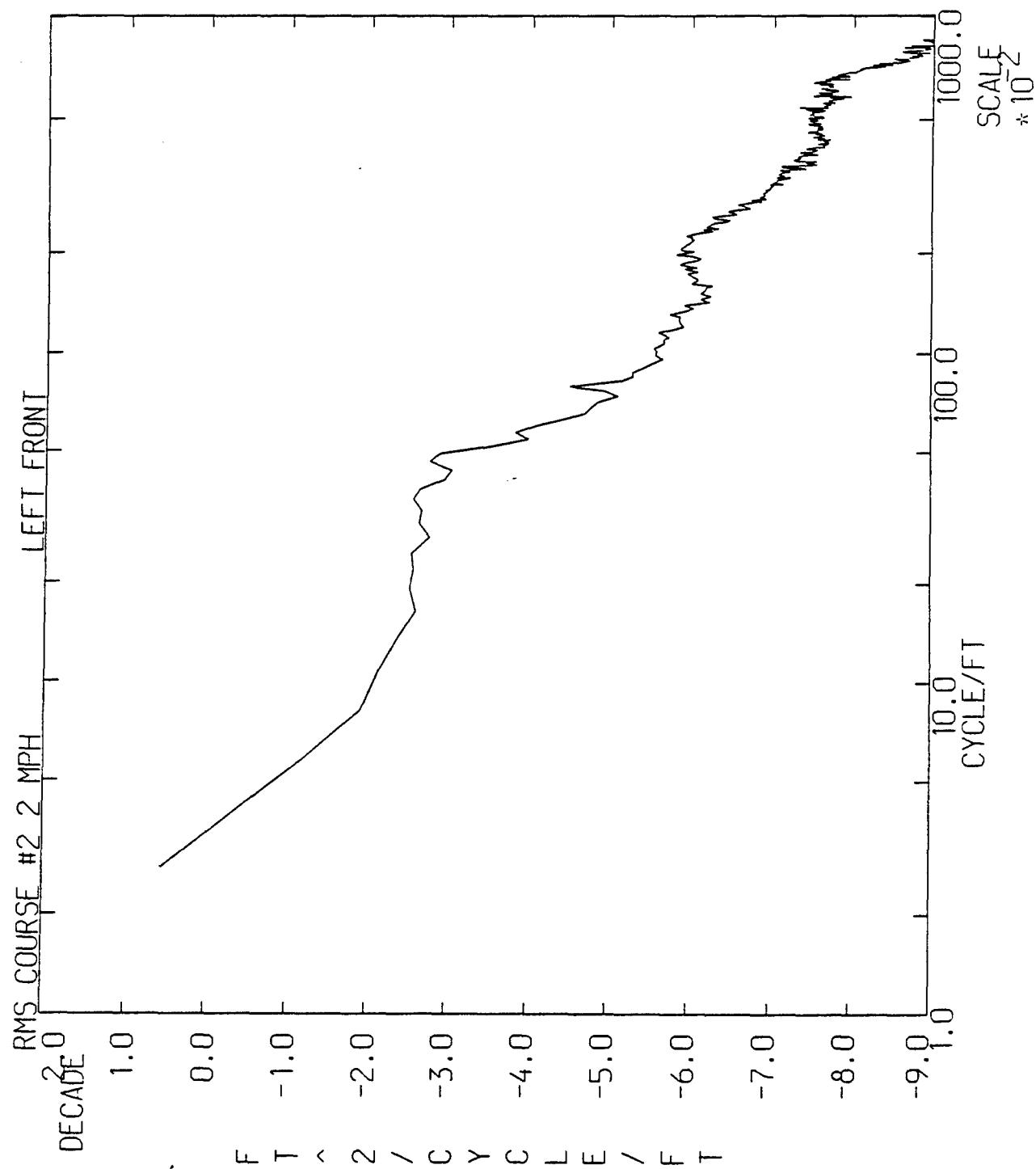
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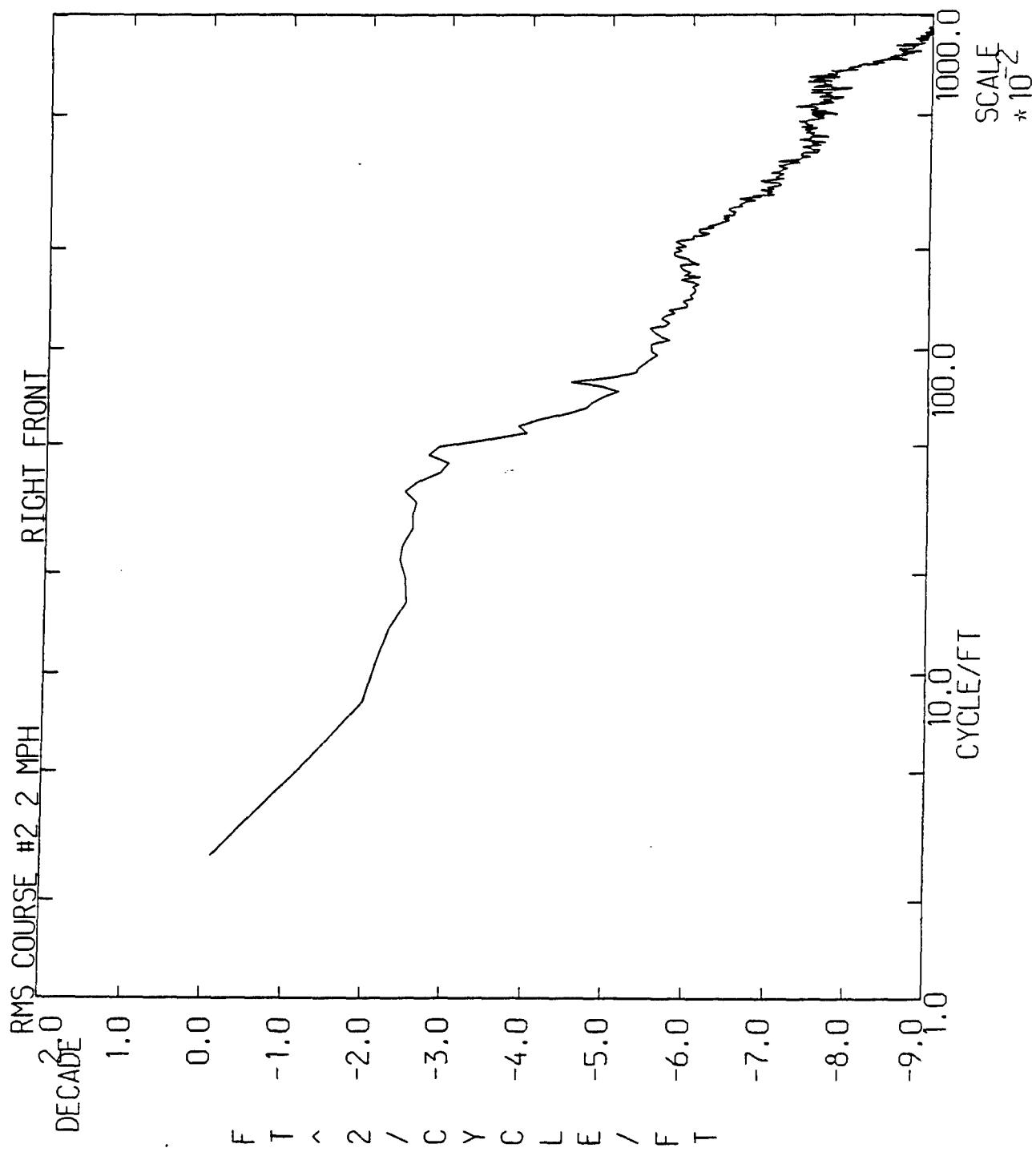
Table 1. DFMV Actual Versus Predicted Wavelength Limits

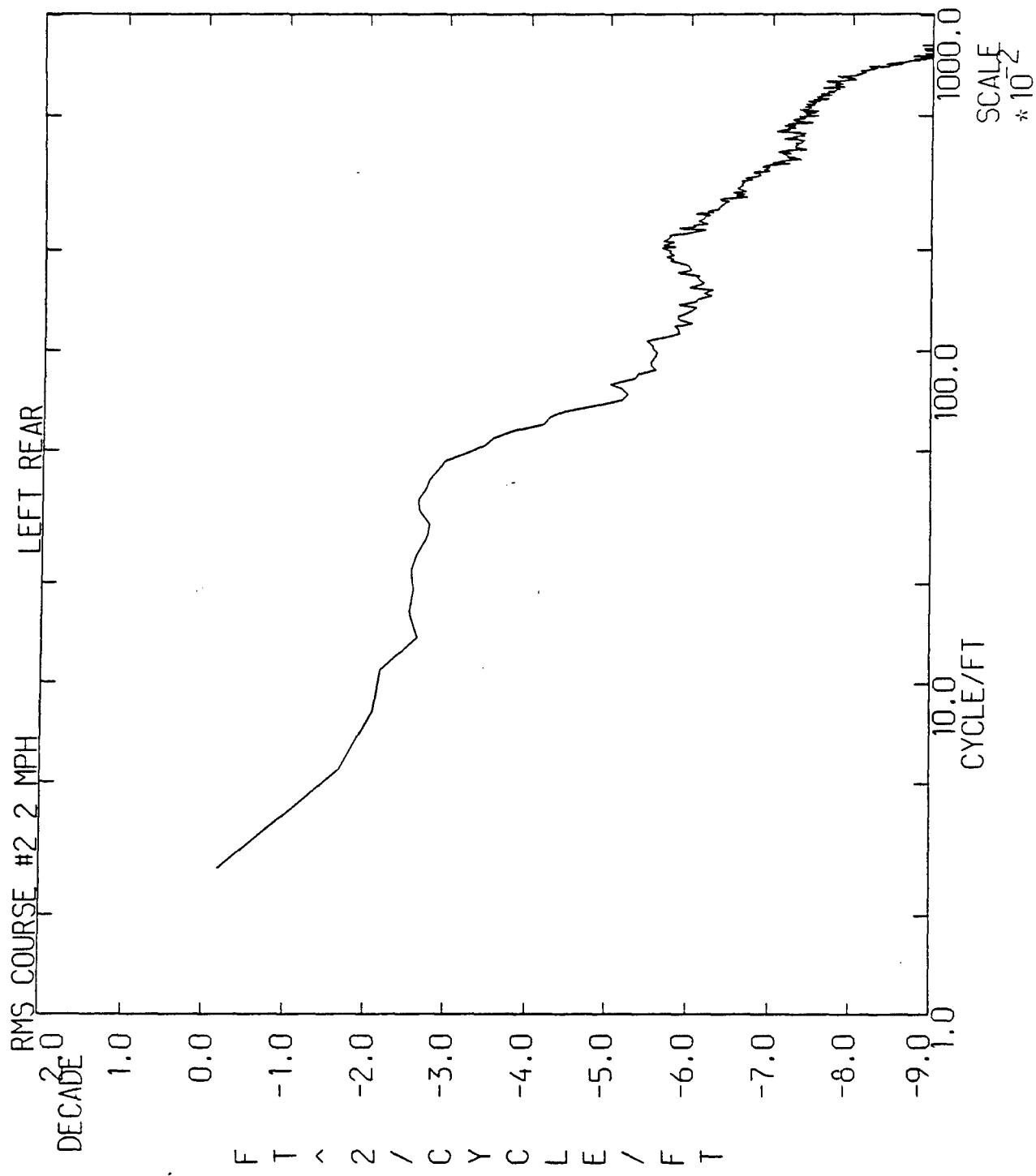
DFMV Speed MPH	Expected Wavelength Resolution*	Actual Wavelength Resolution**
2	60	15
4	120	30
6	180	45
8	240	60
10	300	75

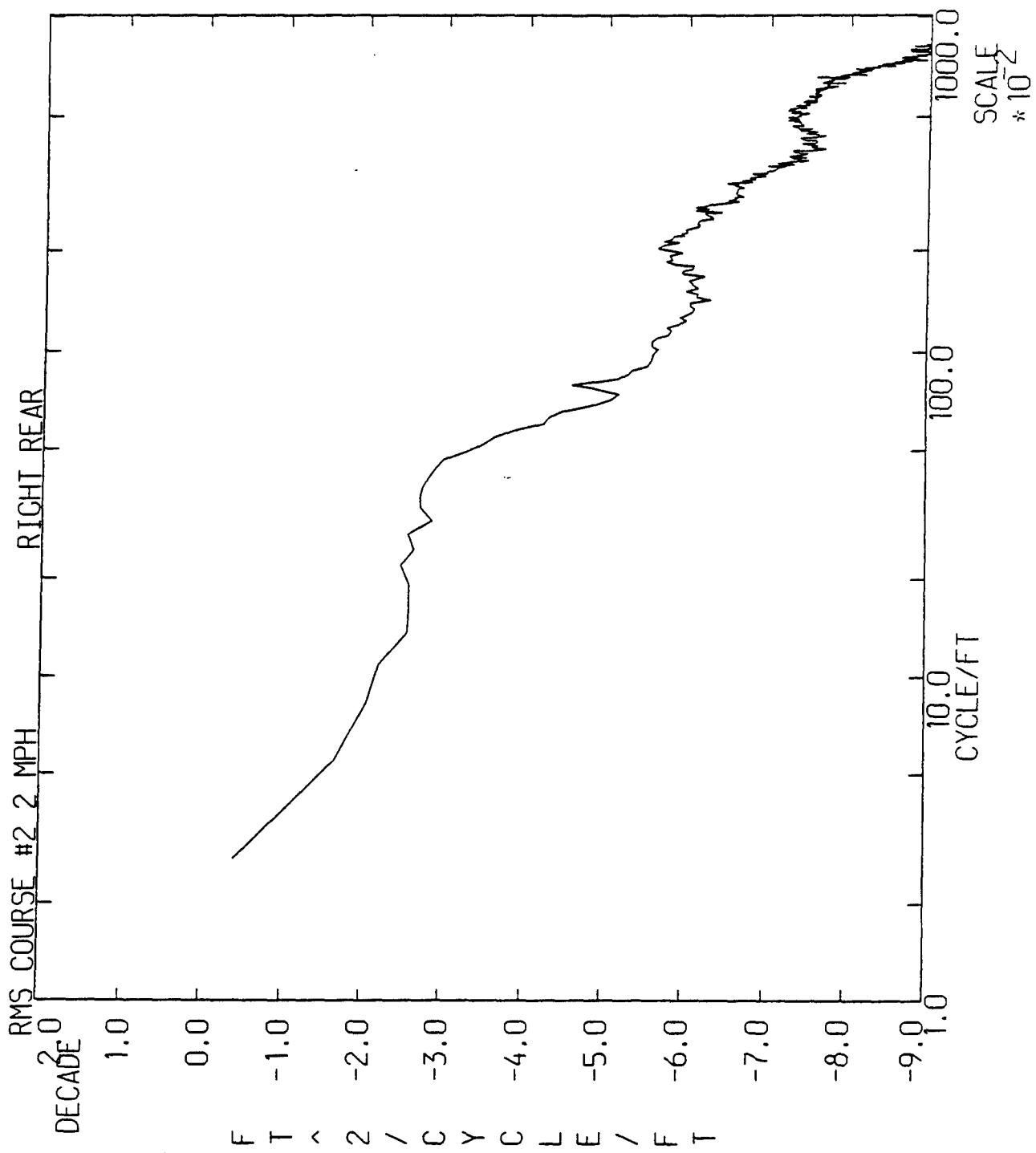
* Based on the advertised low-end frequency range for the accelerometer used

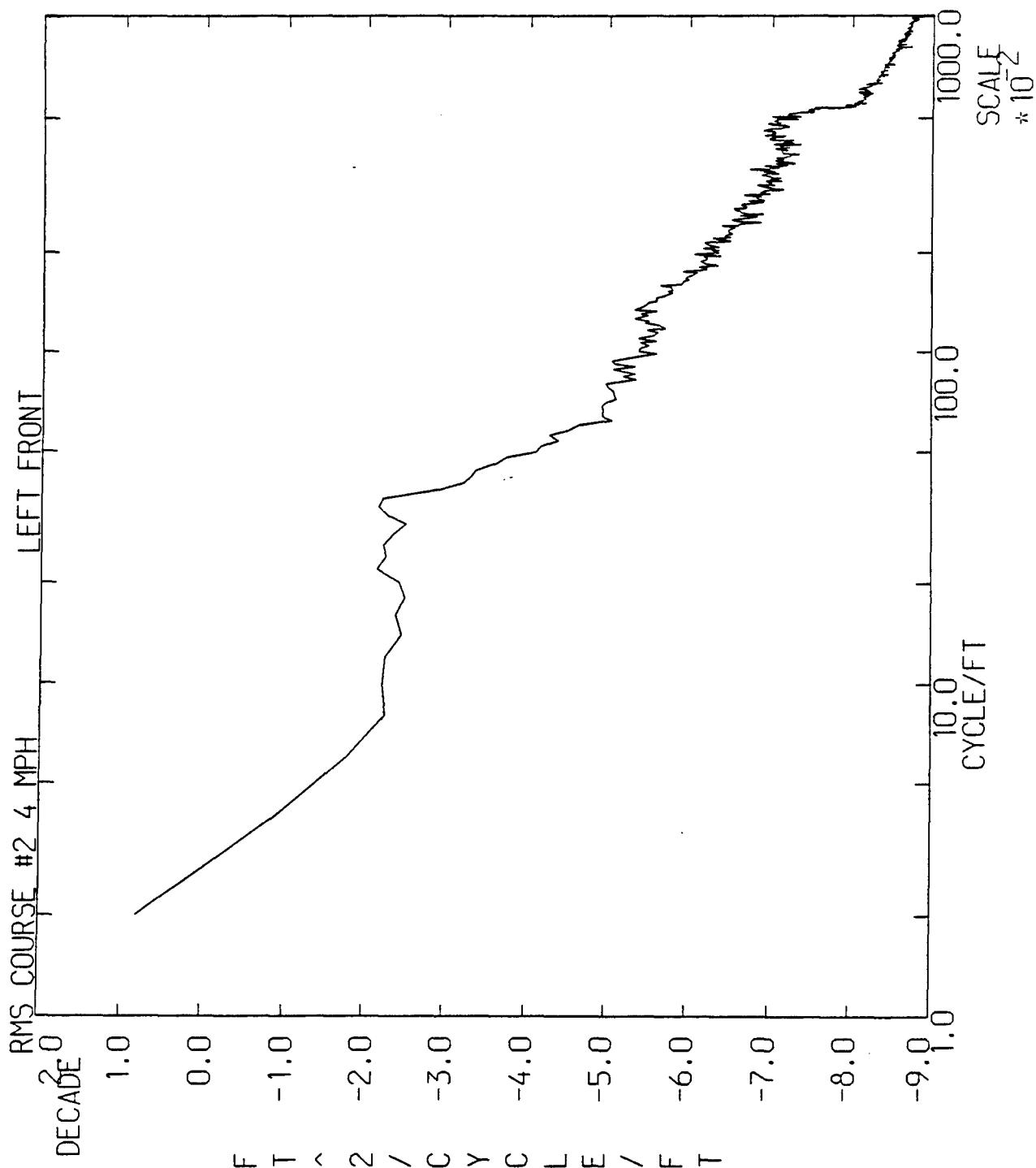
** Based on actual low-end frequency range for the accelerometer used

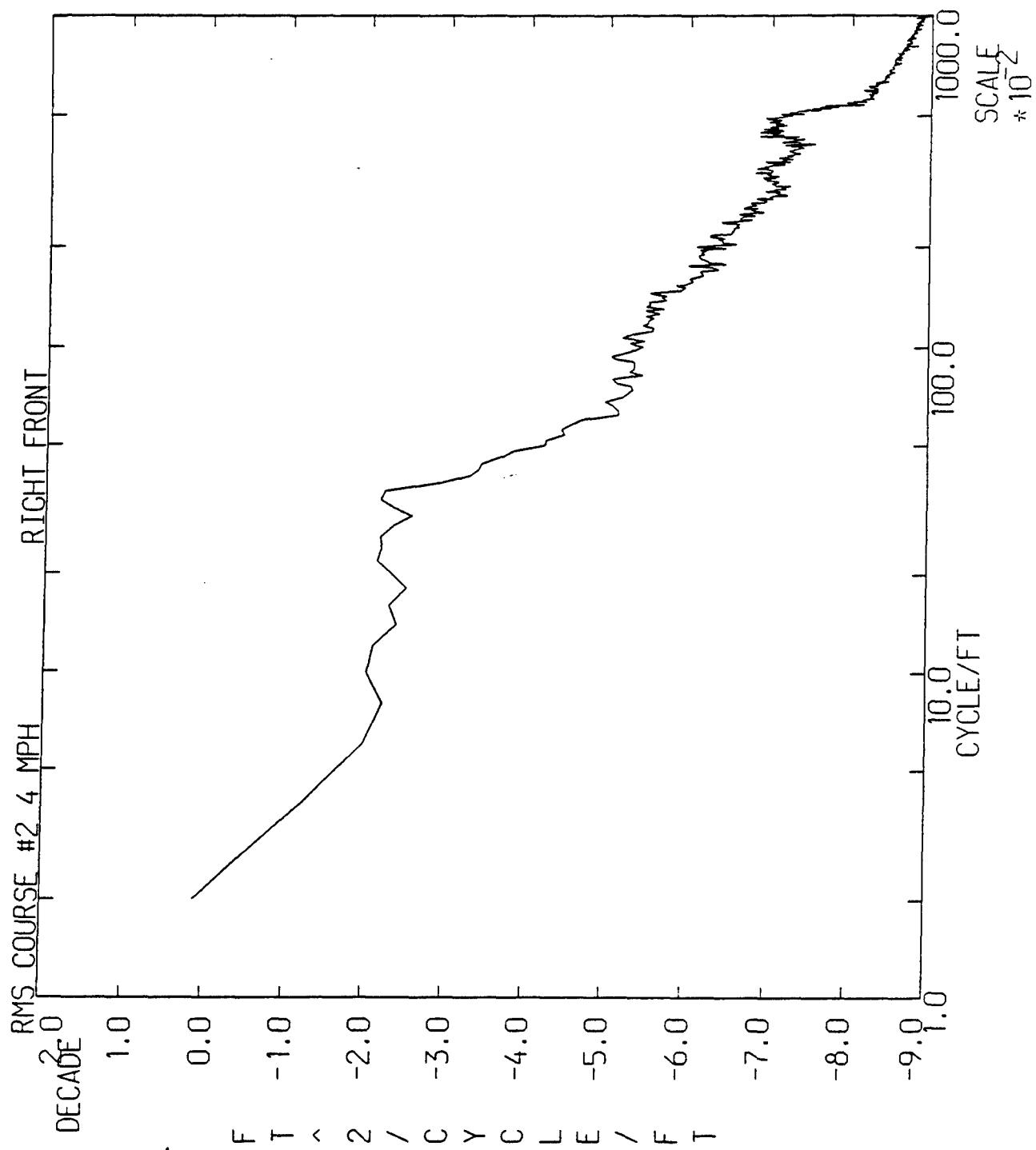


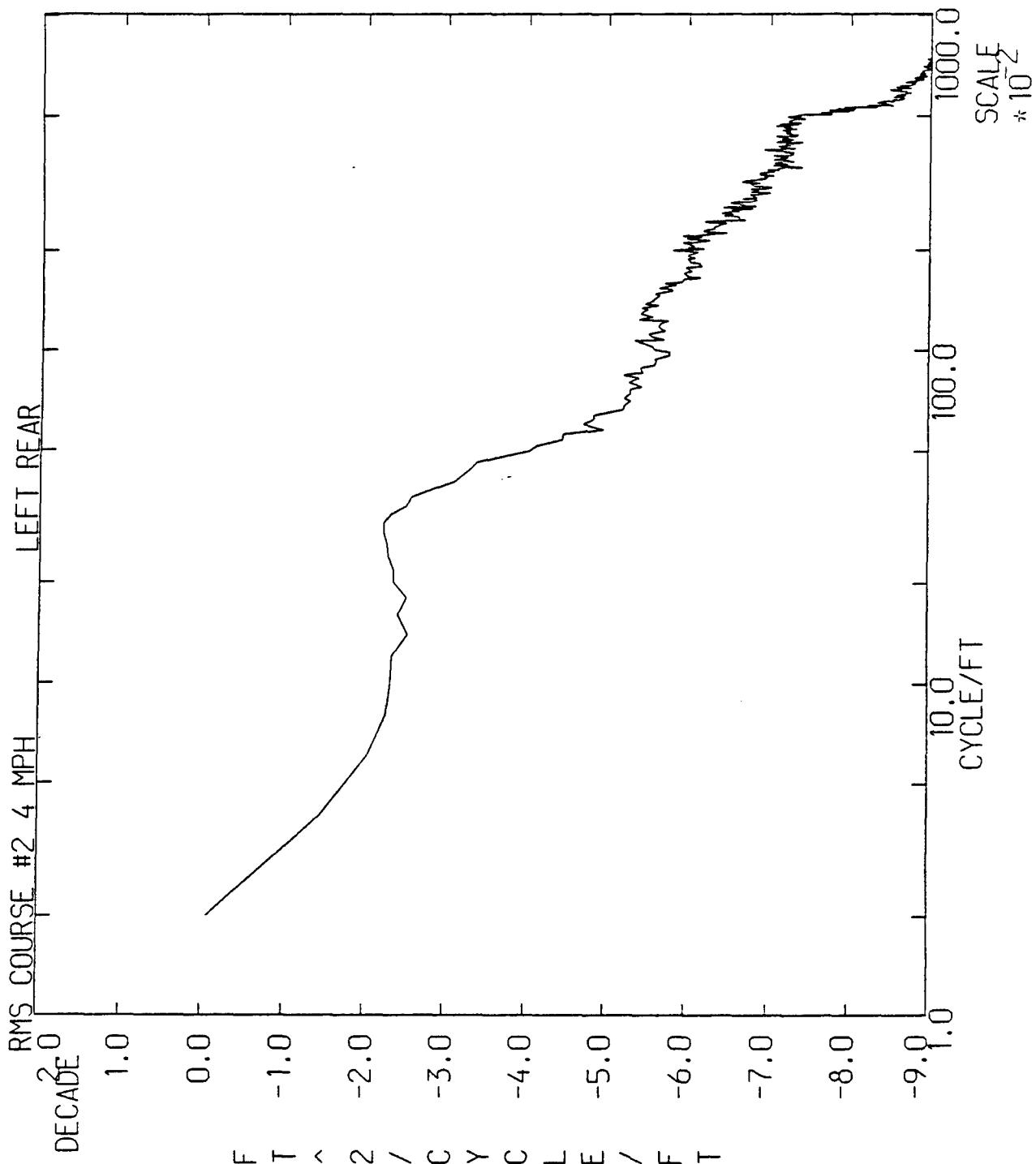


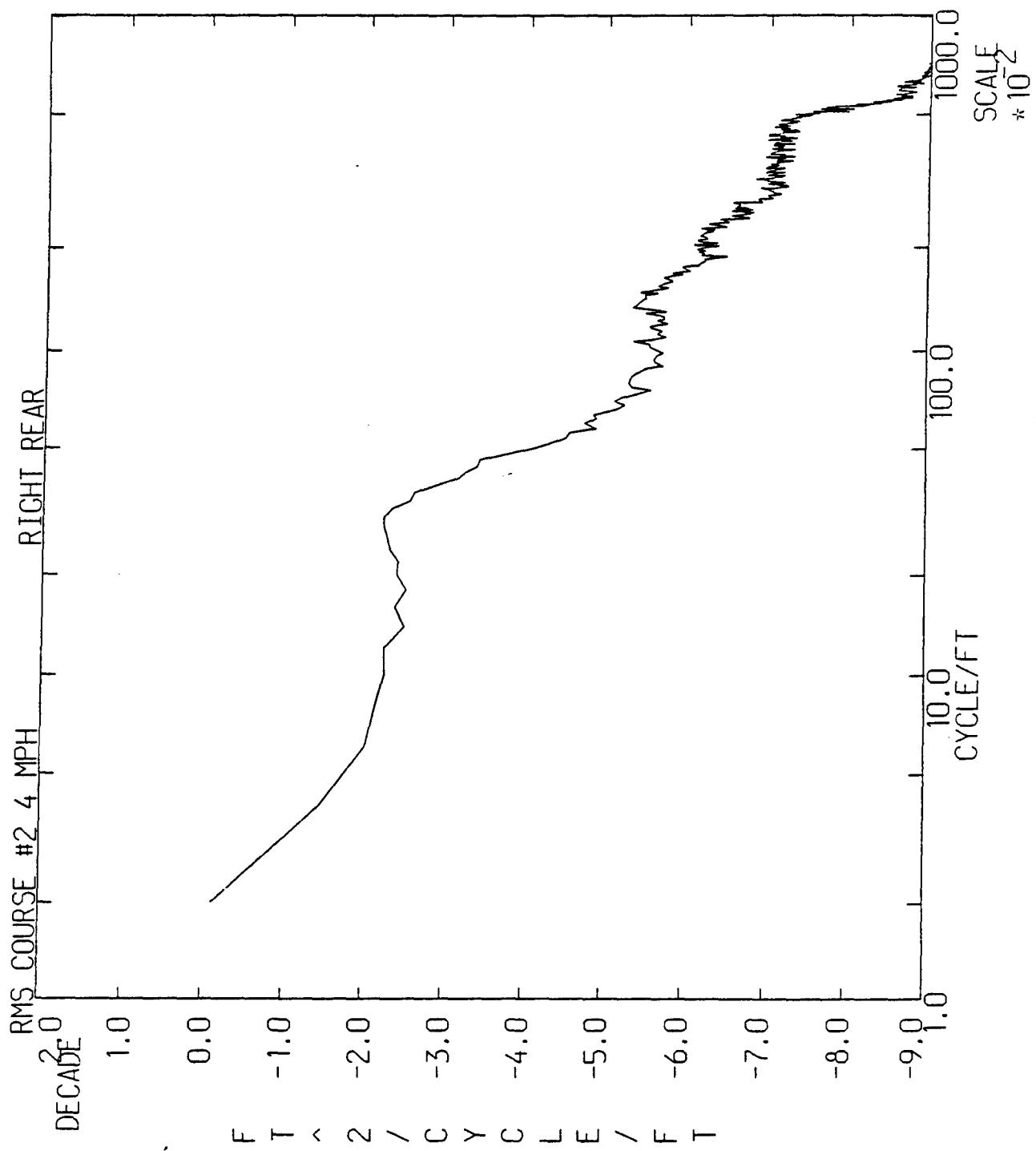


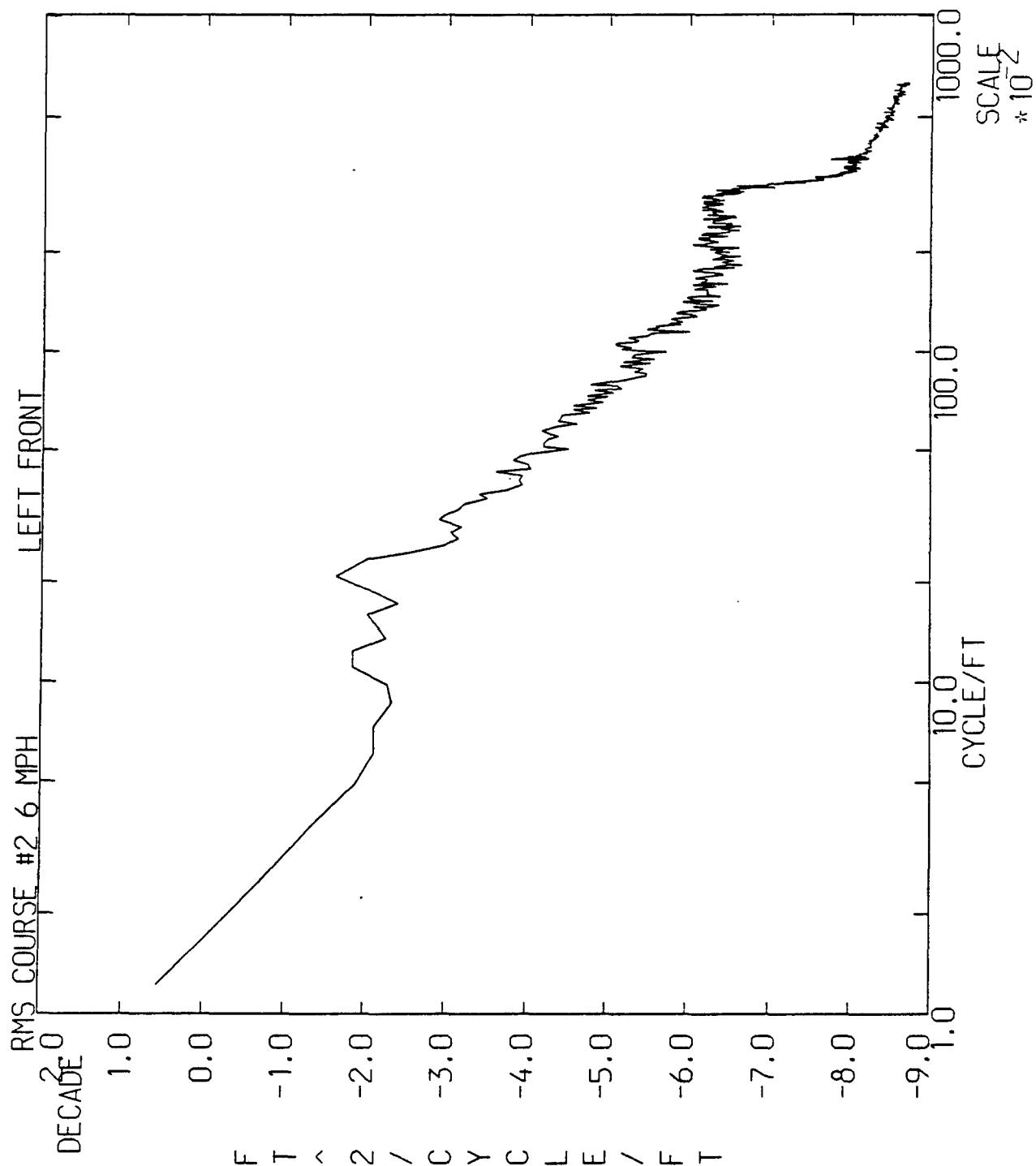


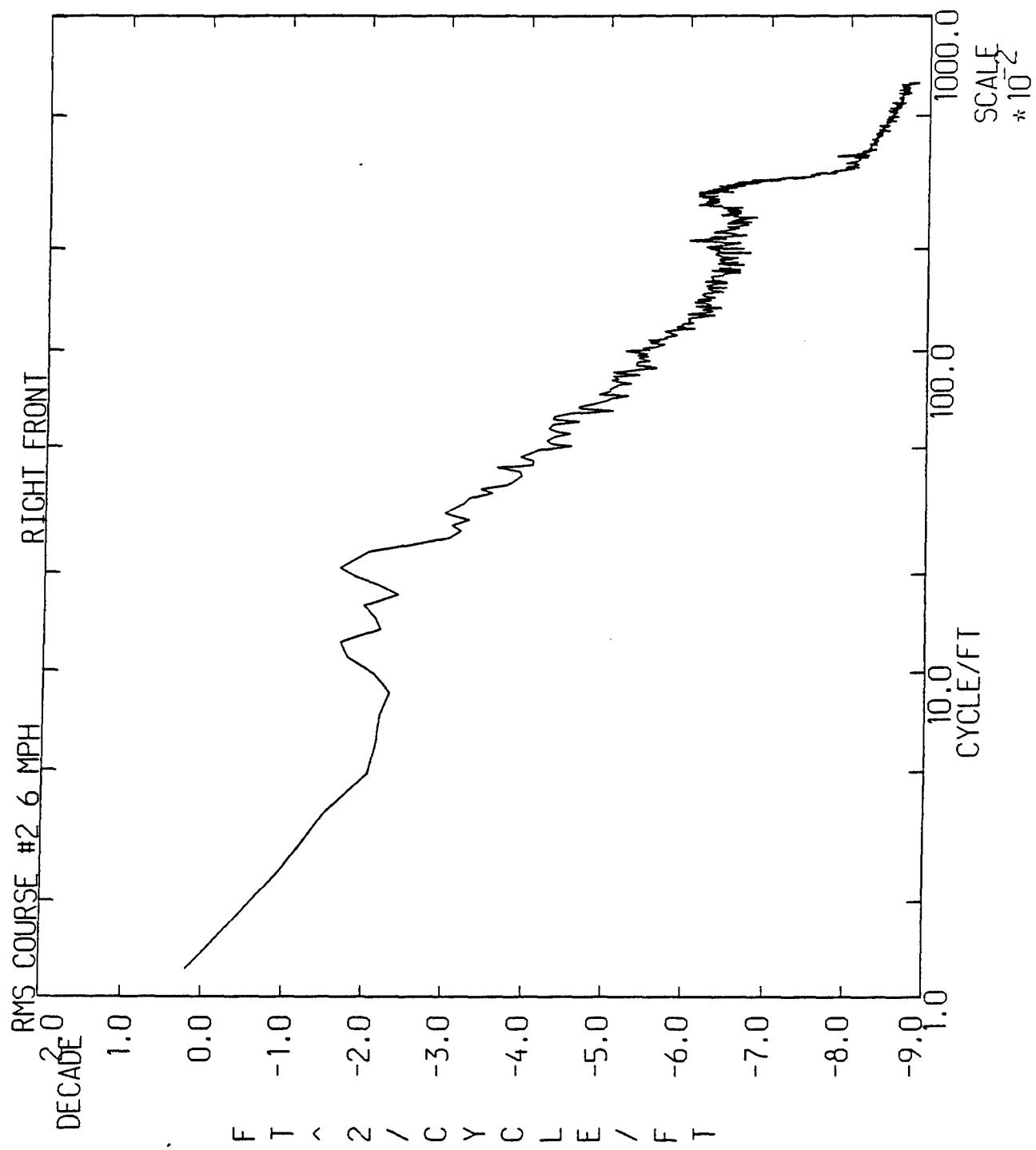


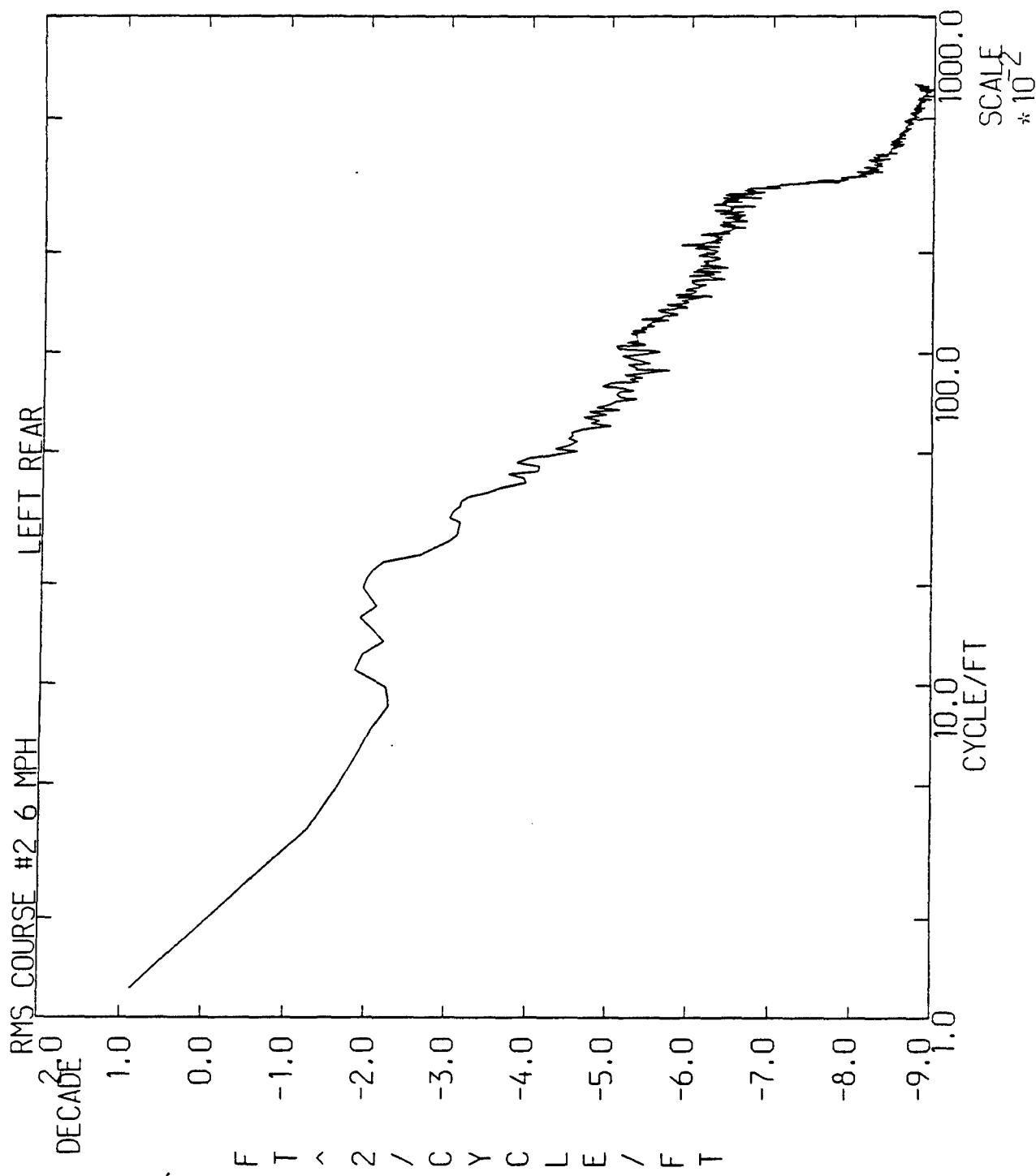


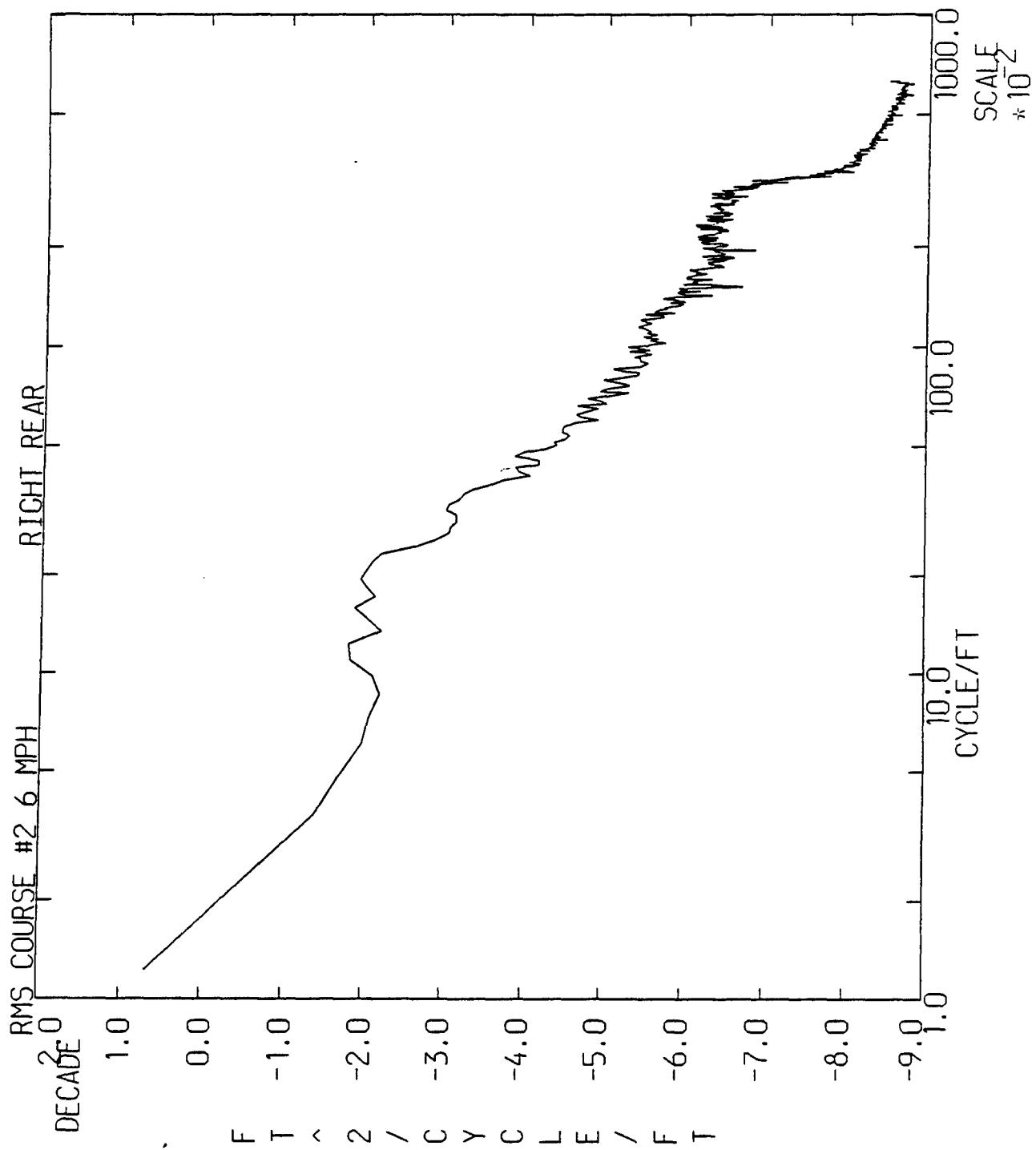


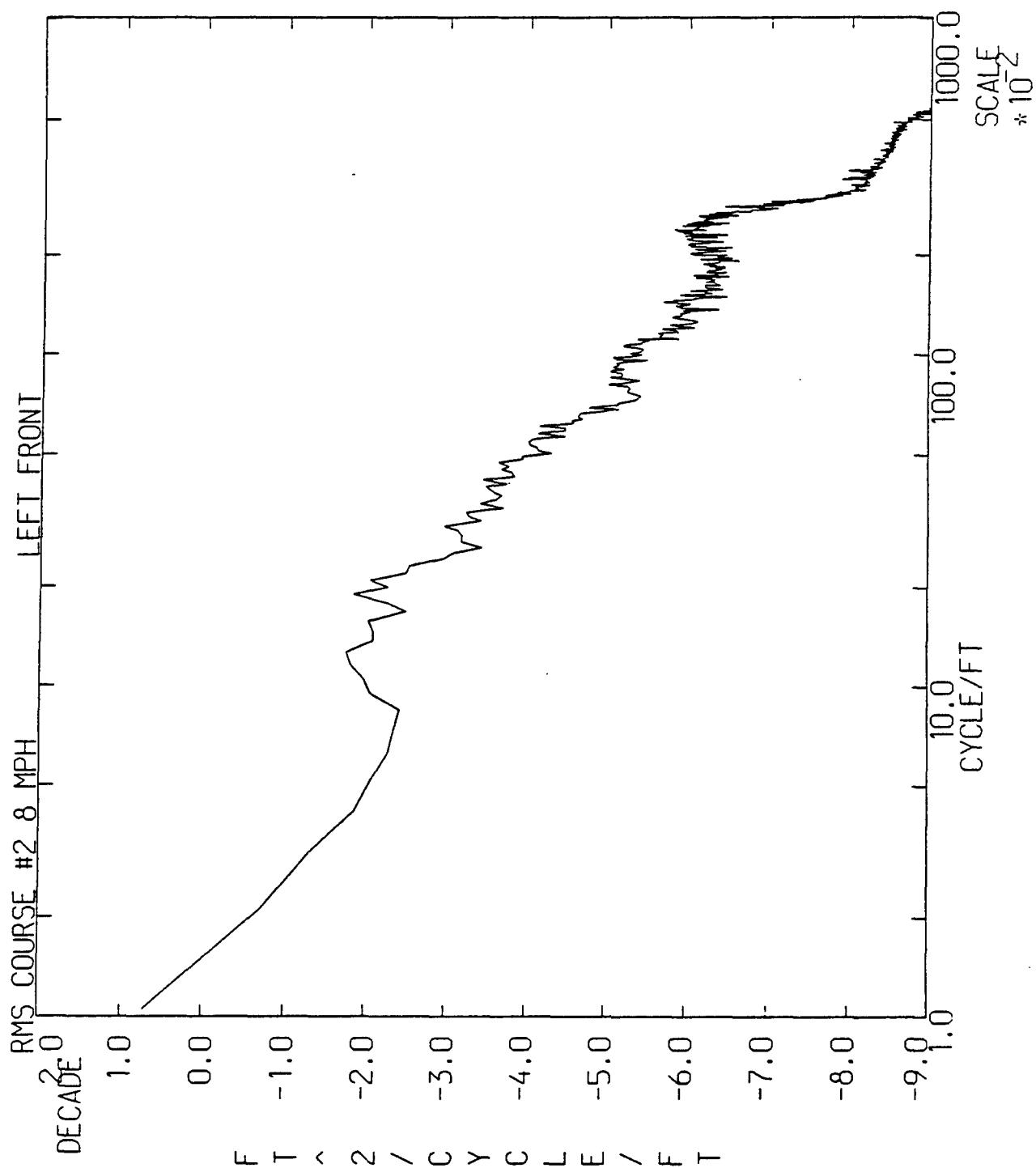


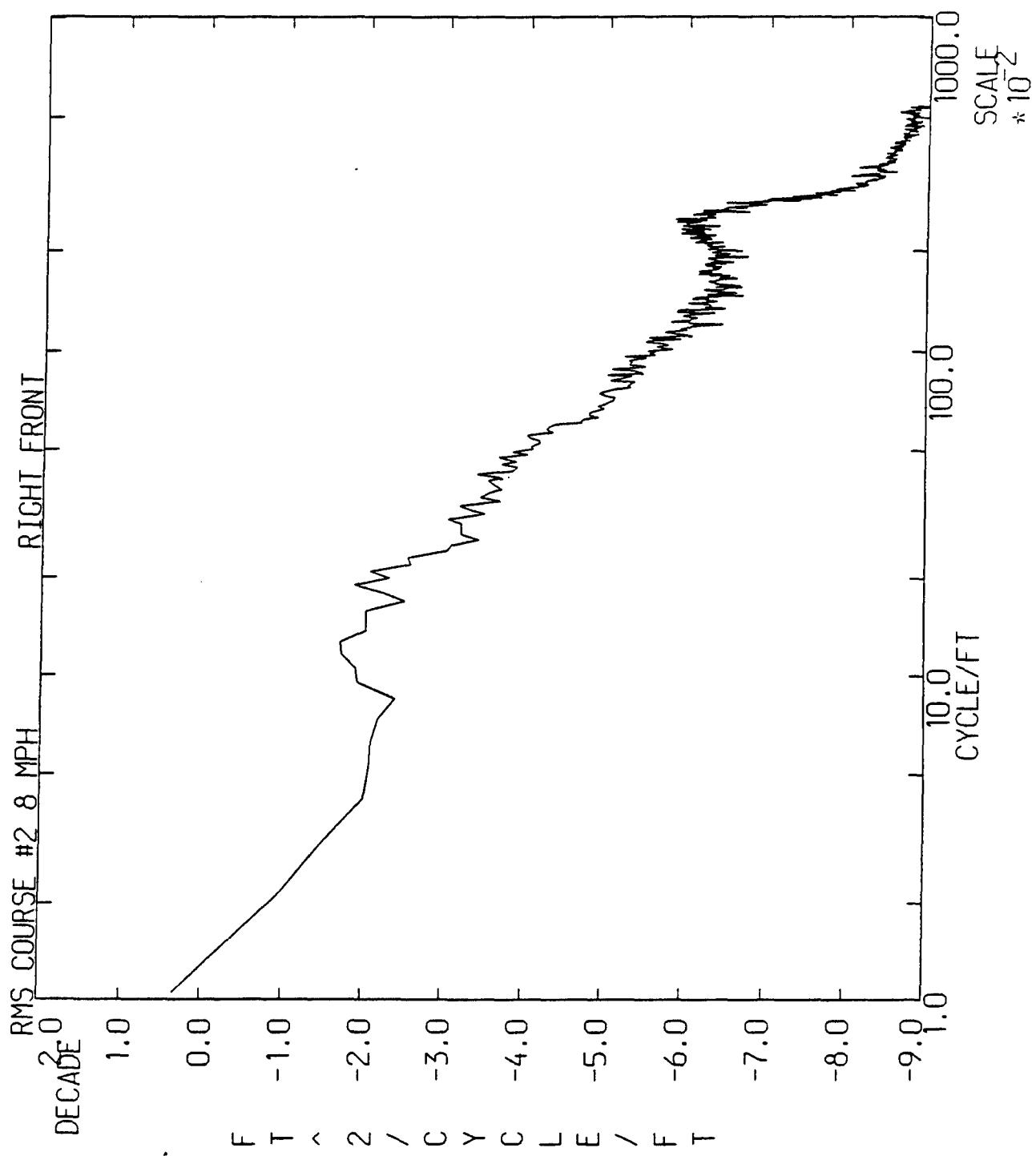


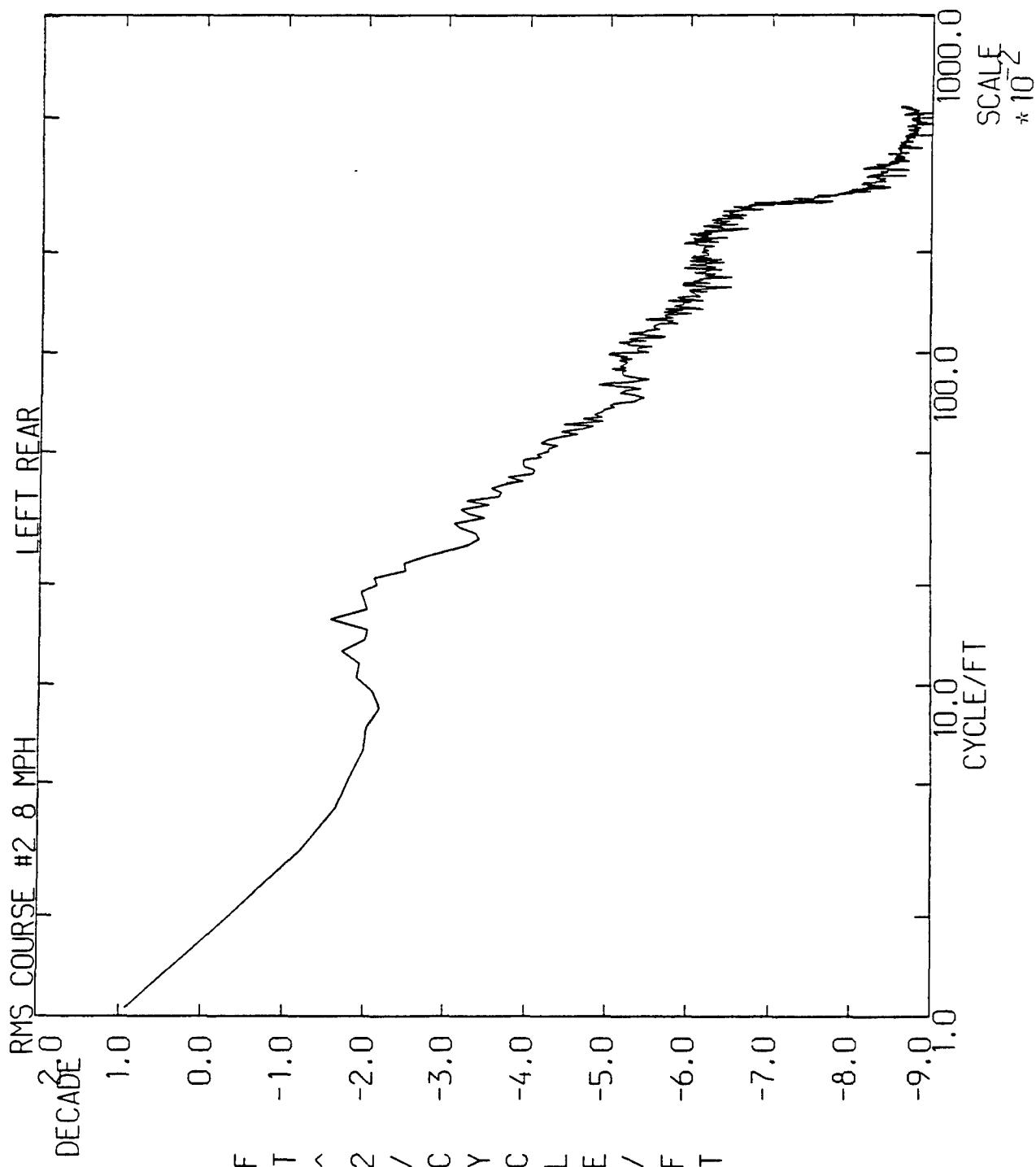


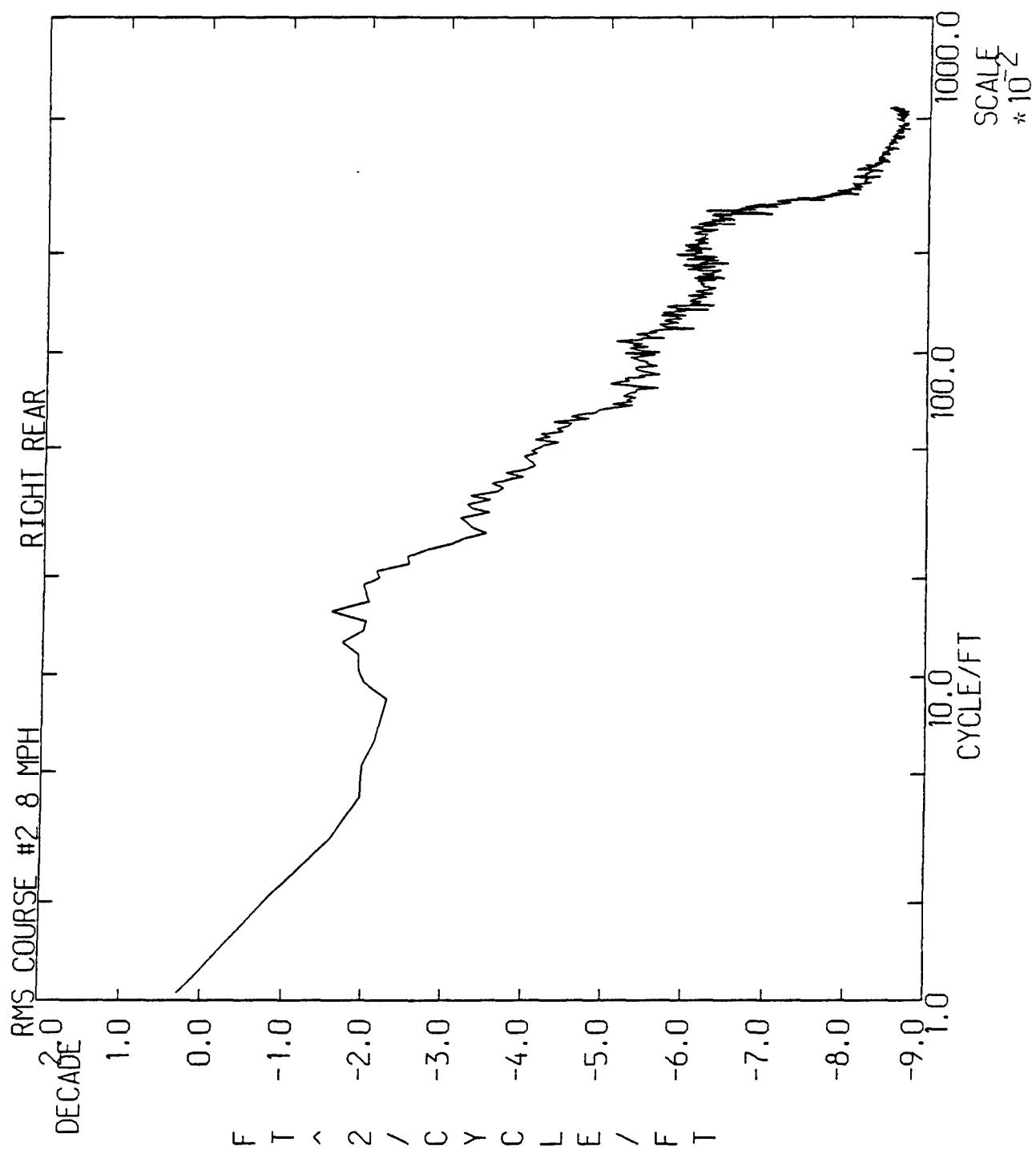


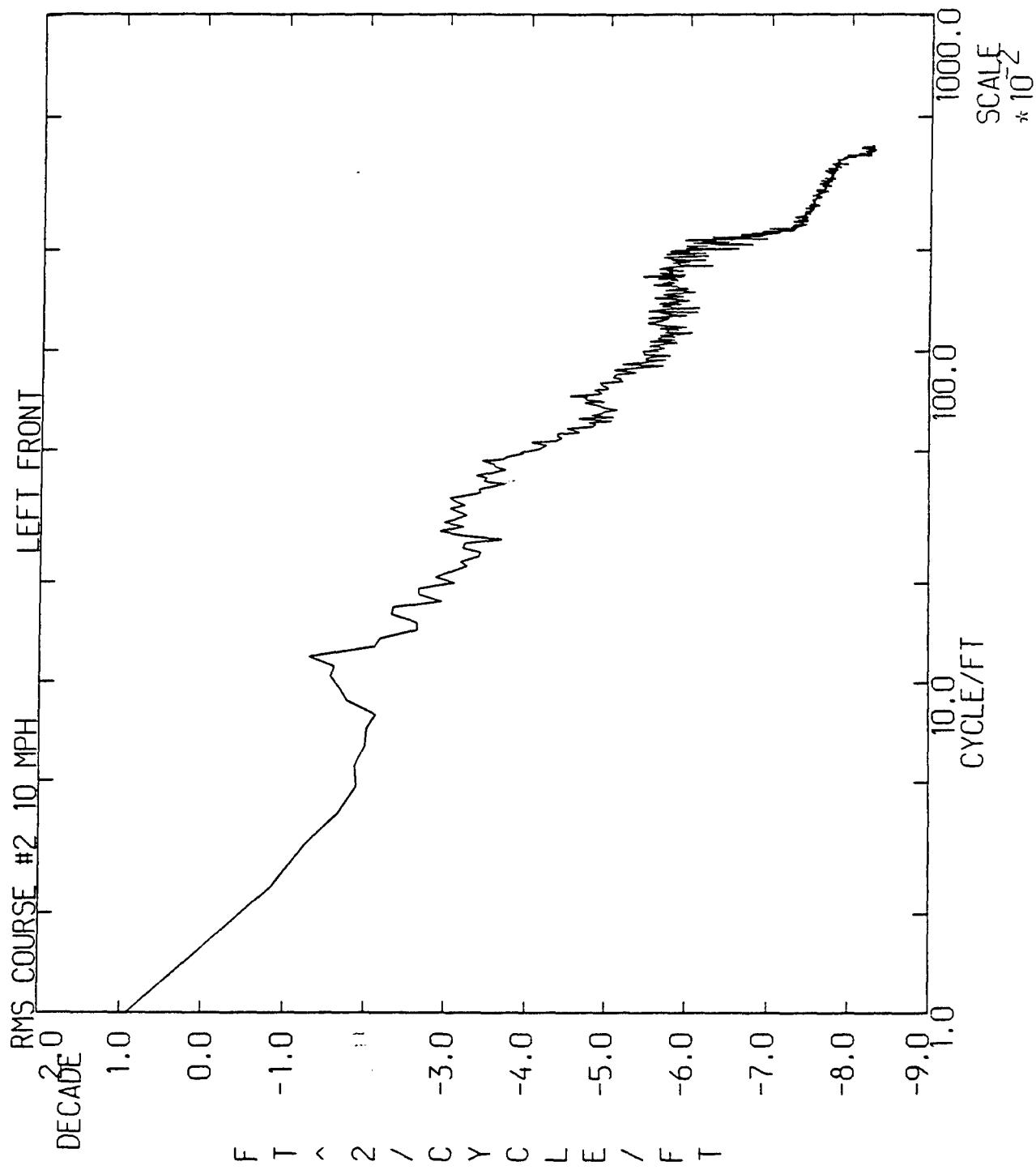




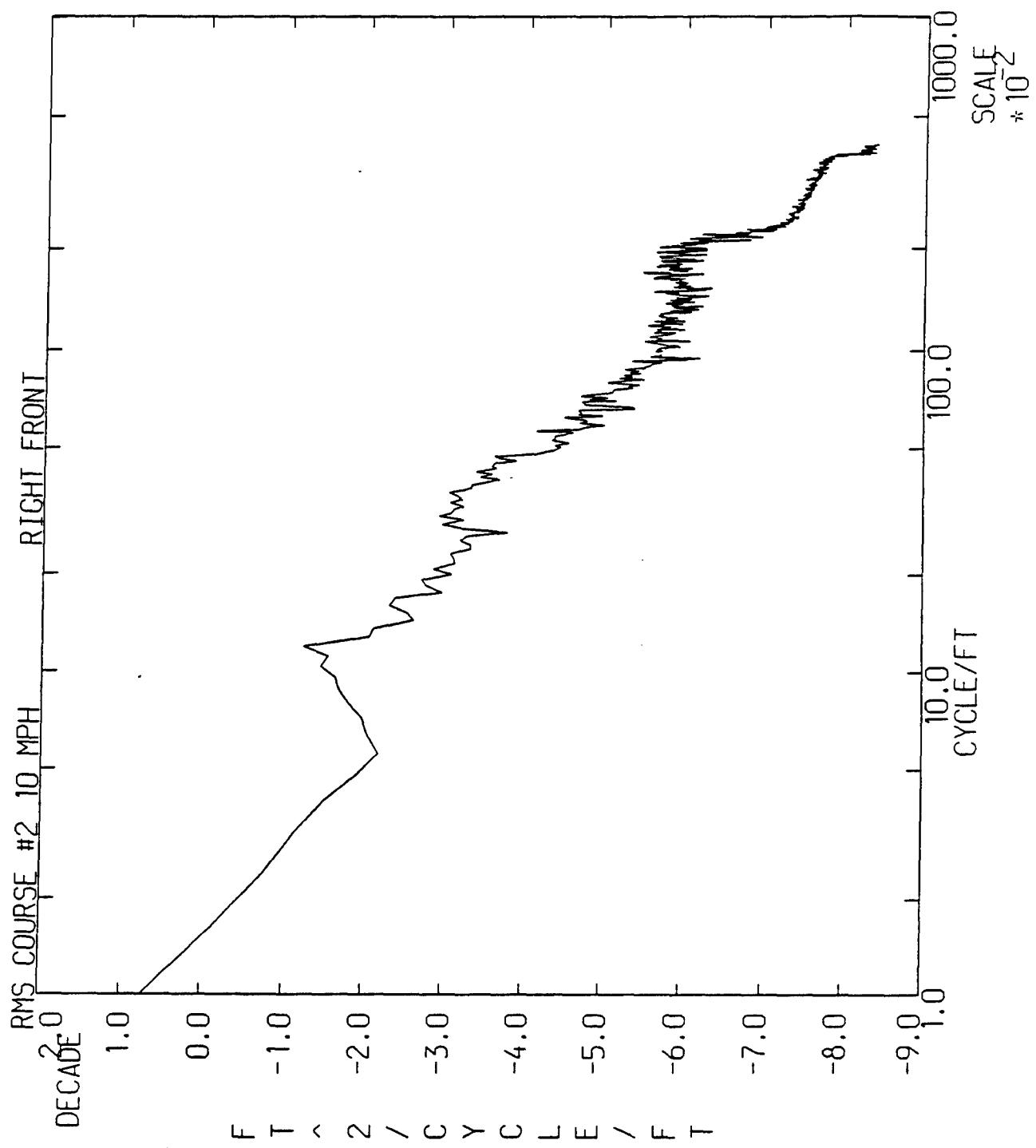




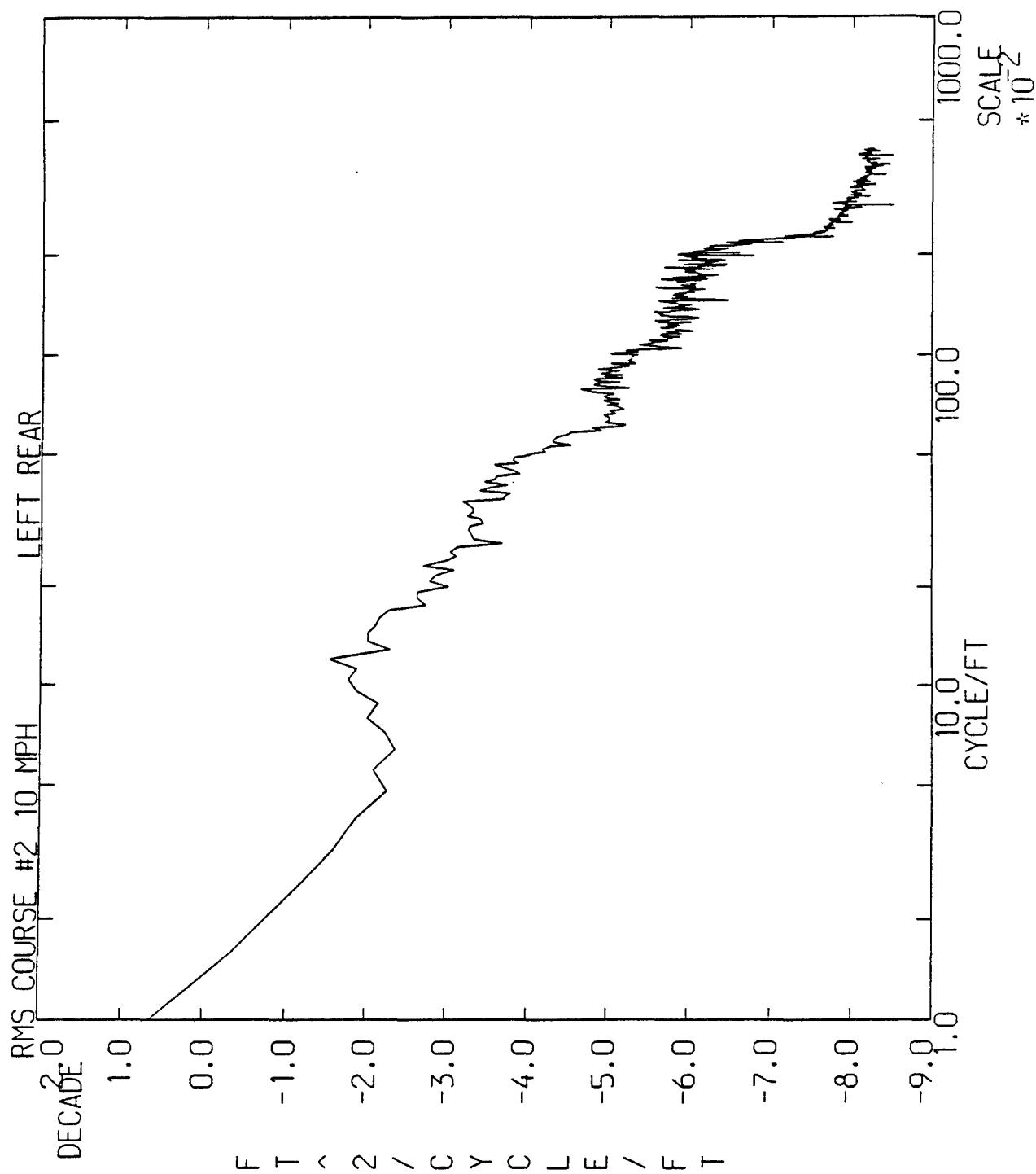


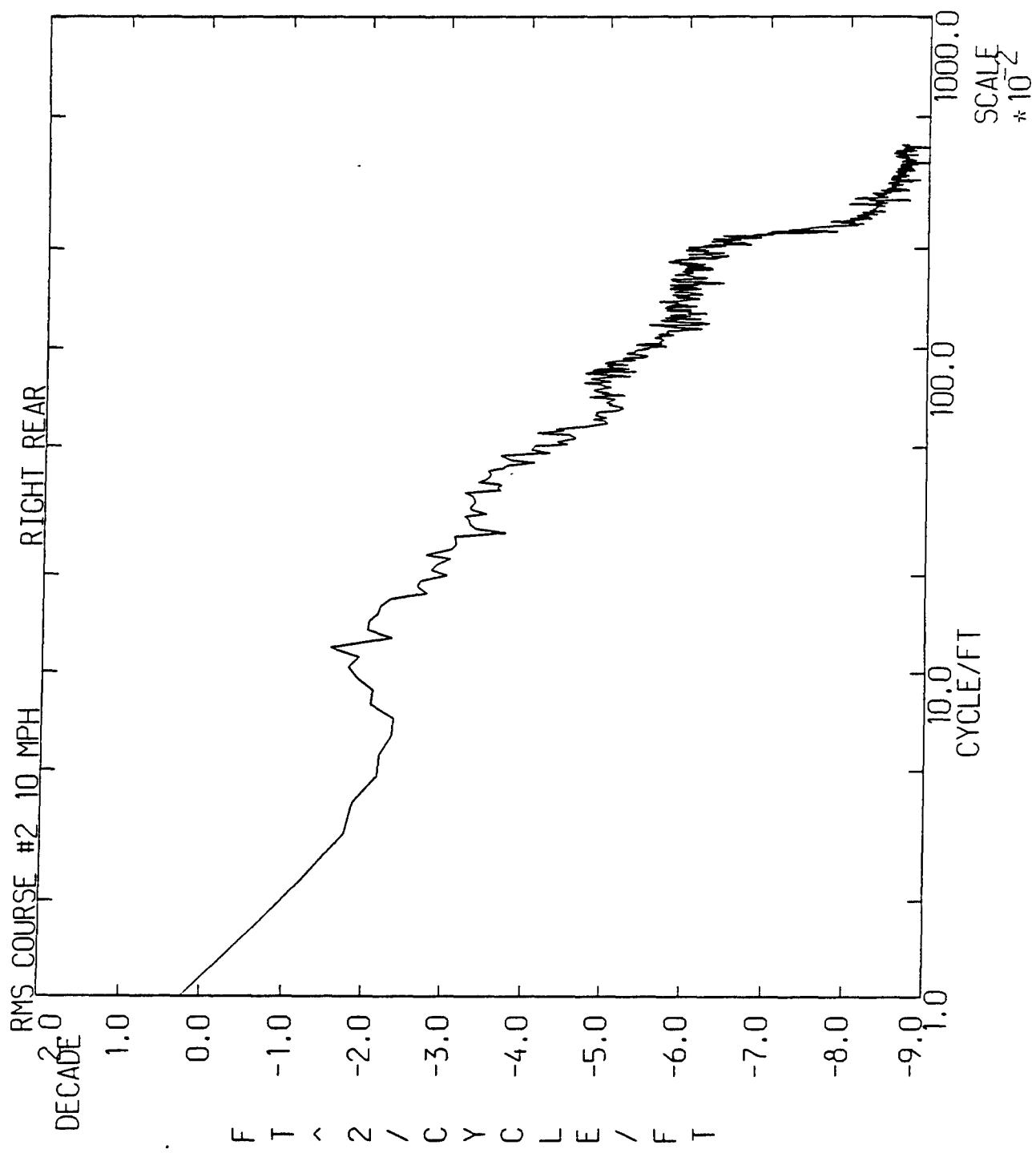


069



070





WASHBOARD COURSE

WAVE-NUMBER SPECTRA

2, 4, 6, 8 and 10 MPH

Four (4) curves per speed, one for each DFMV tire, as follows

LEFT FRONT
RIGHT FRONT
LEFT REAR
RIGHT REAR

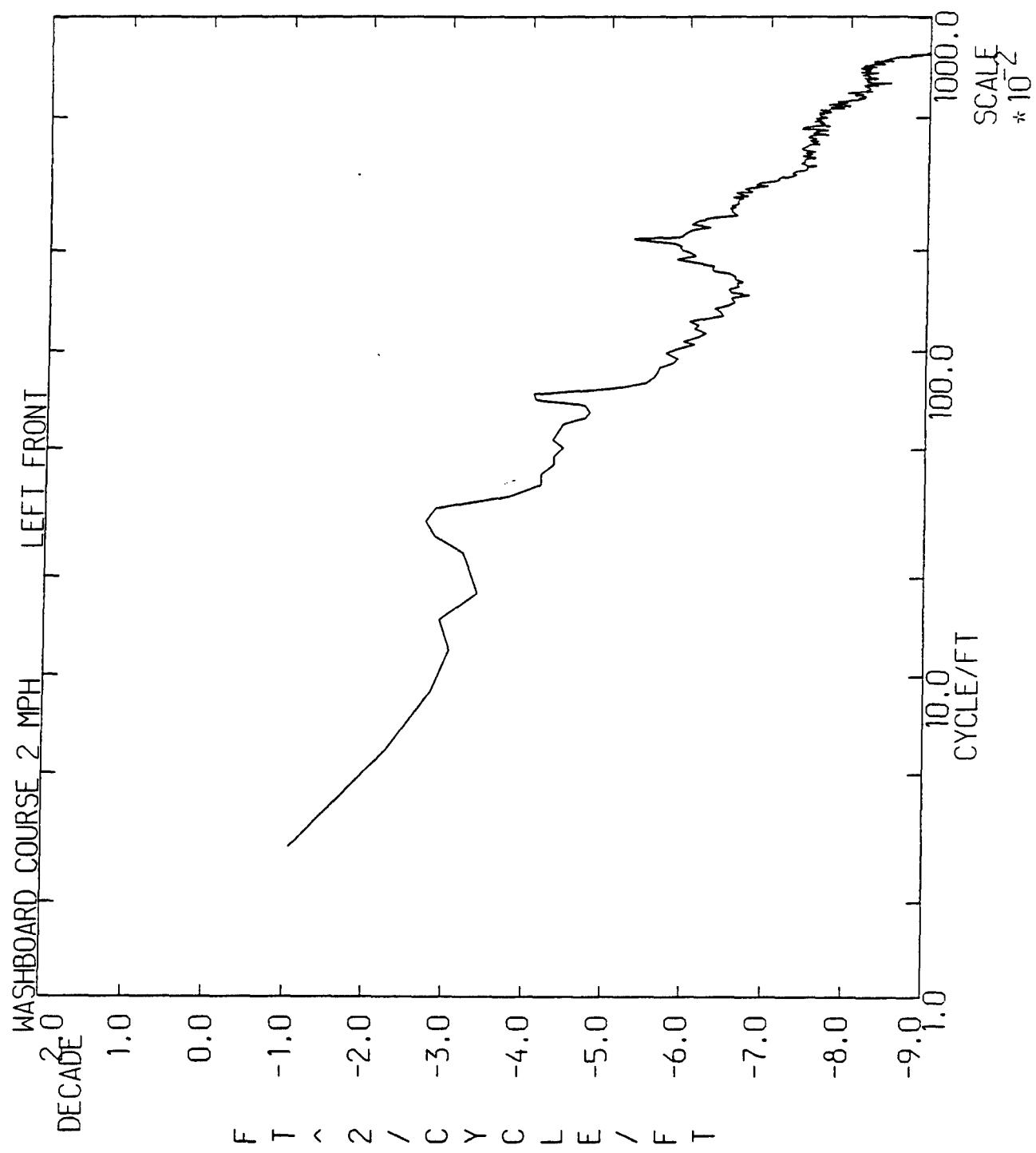
Volume II contains the data for the different DFMV speeds over each YPG course. The data was previously submitted to TACOM in an interim data report, however, the data was not reprocessed with the signal processing considerations discussed in the Volume I report (e.g., in this data, much of the spectral resolution was below the footprint). The wave-number cut-off at the low end of the spectra was limited by the frequency range of the accelerometer, as discussed in the report and shown in the table below. The wave-number cut-off at the high end of the spectrum was limited by the footprint length of the DFMV tire, which was $\approx 1.2 \text{ ft}^{-1}$. These cut-offs were verified through the DFMV front-to-rear coherence plots. Therefore, when comparing plots between different speeds, do not compare the data past these limits. As discussed in the report, the faster speed runs produced the best results at the lower wave numbers.

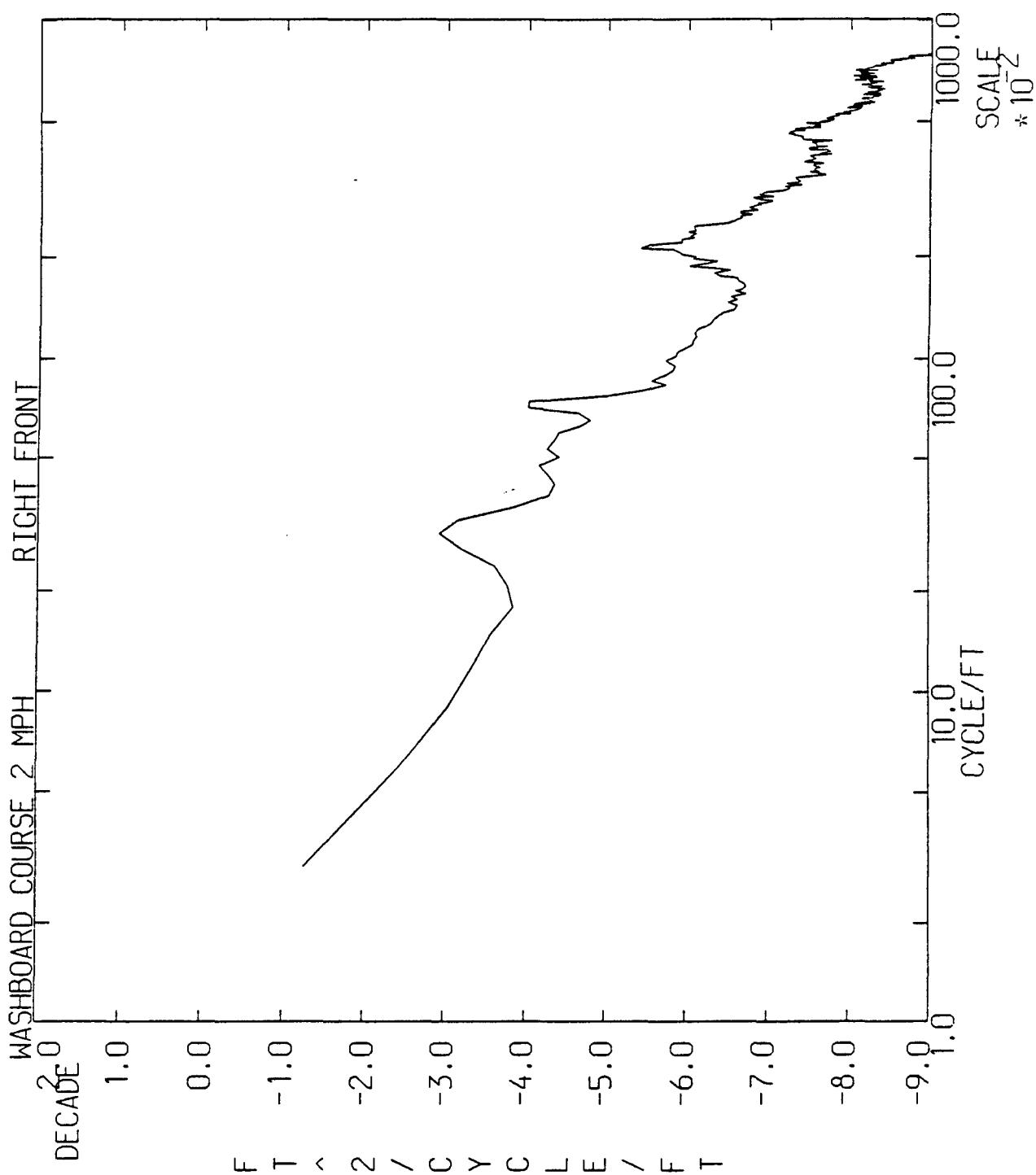
Table 1. DFMV Actual Versus Predicted Wavelength Limits

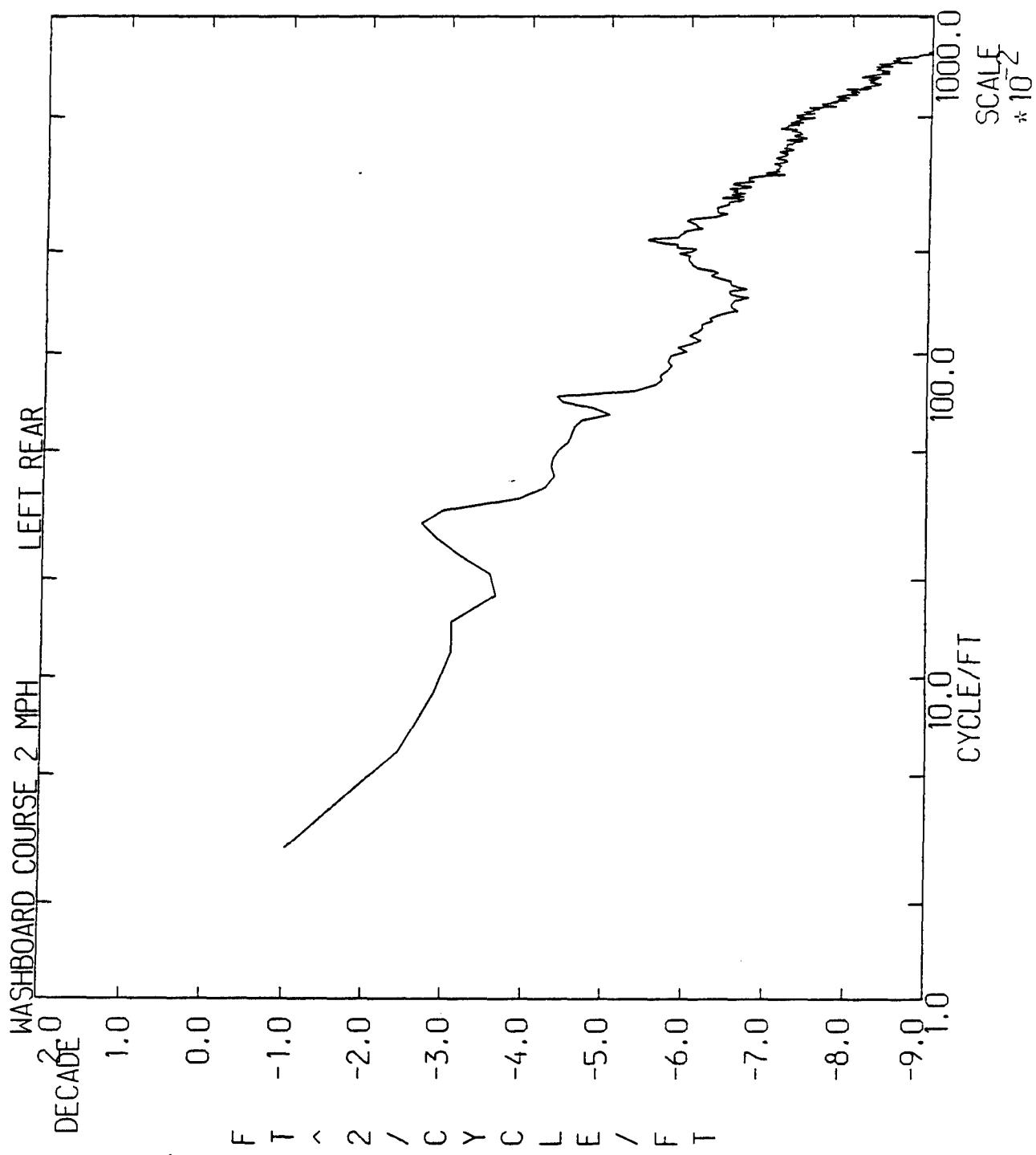
DFMV Speed MPH	Expected Wavelength Resolution*	Actual Wavelength Resolution**
2	60	15
4	120	30
6	180	45
8	240	60
10	300	75

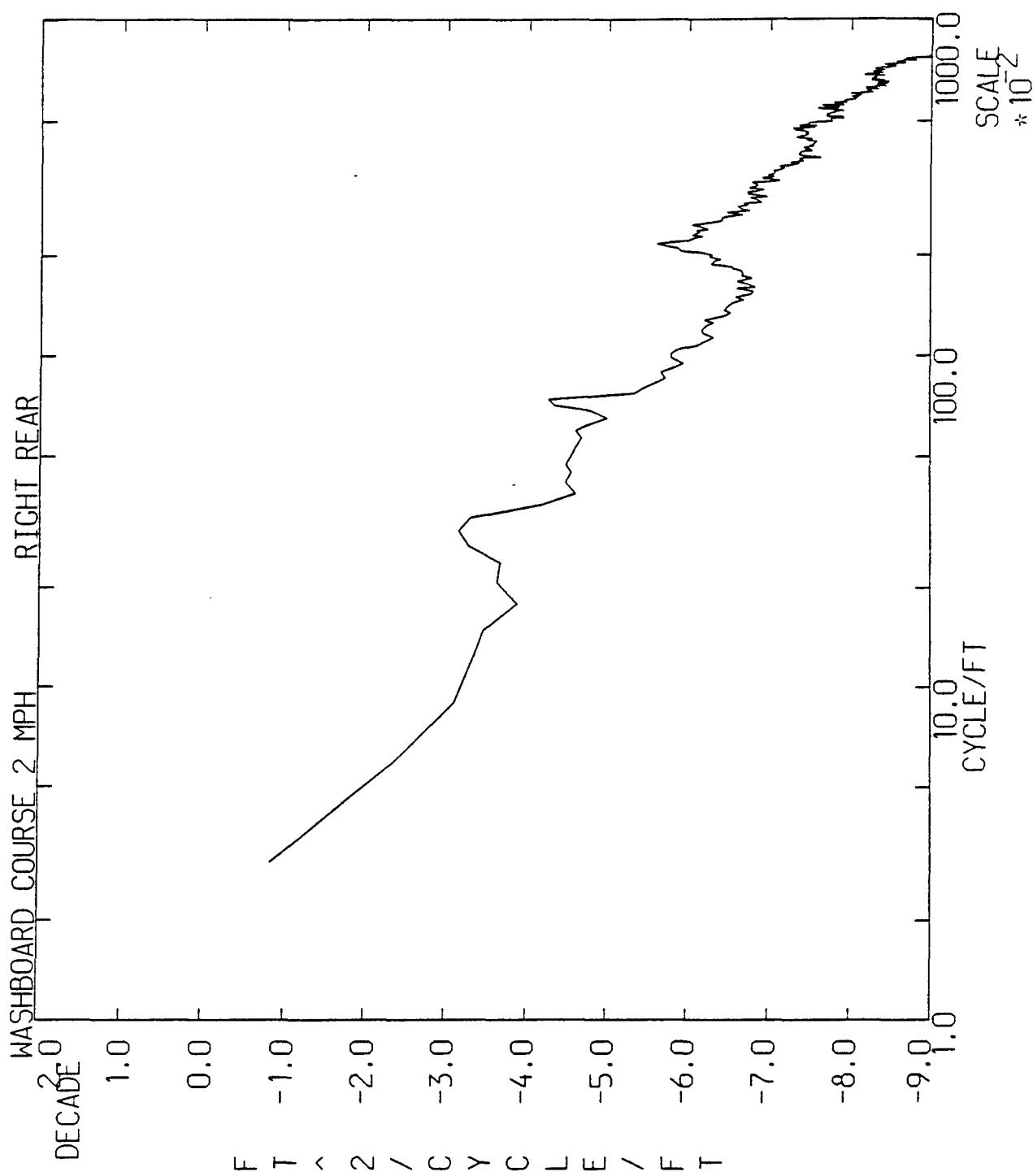
* Based on the advertised low-end frequency range for the accelerometer used

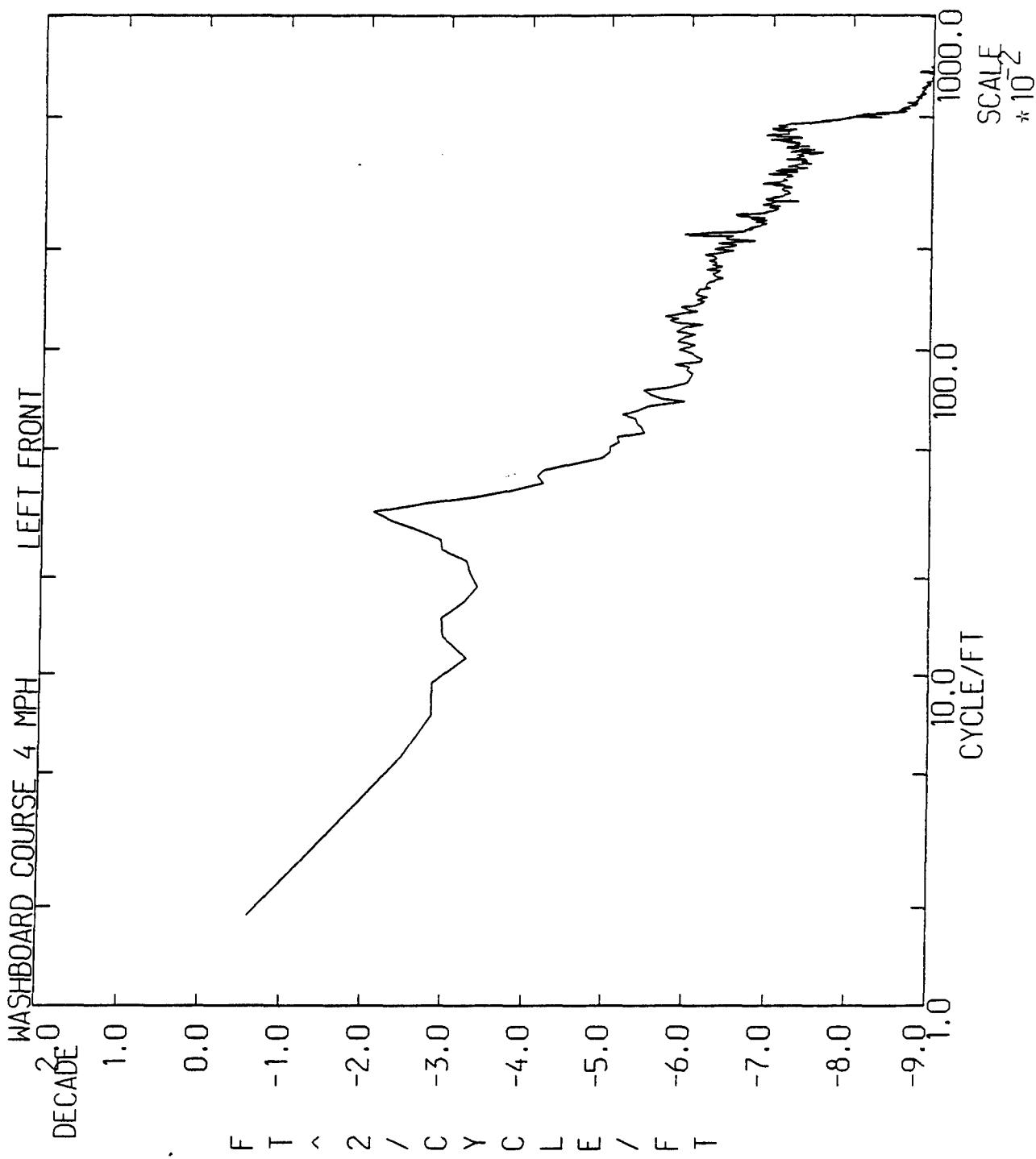
** Based on actual low-end frequency range for the accelerometer used

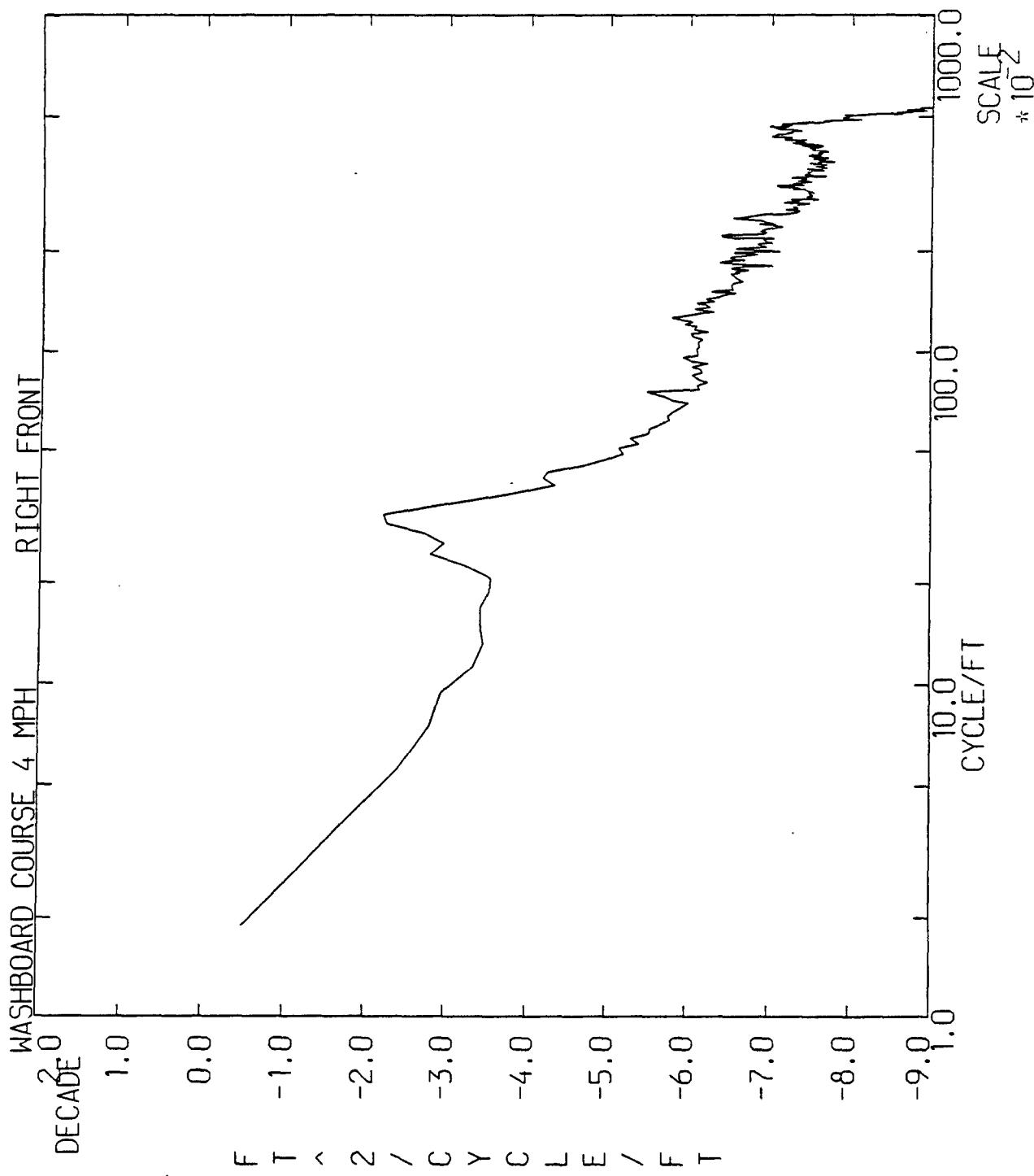


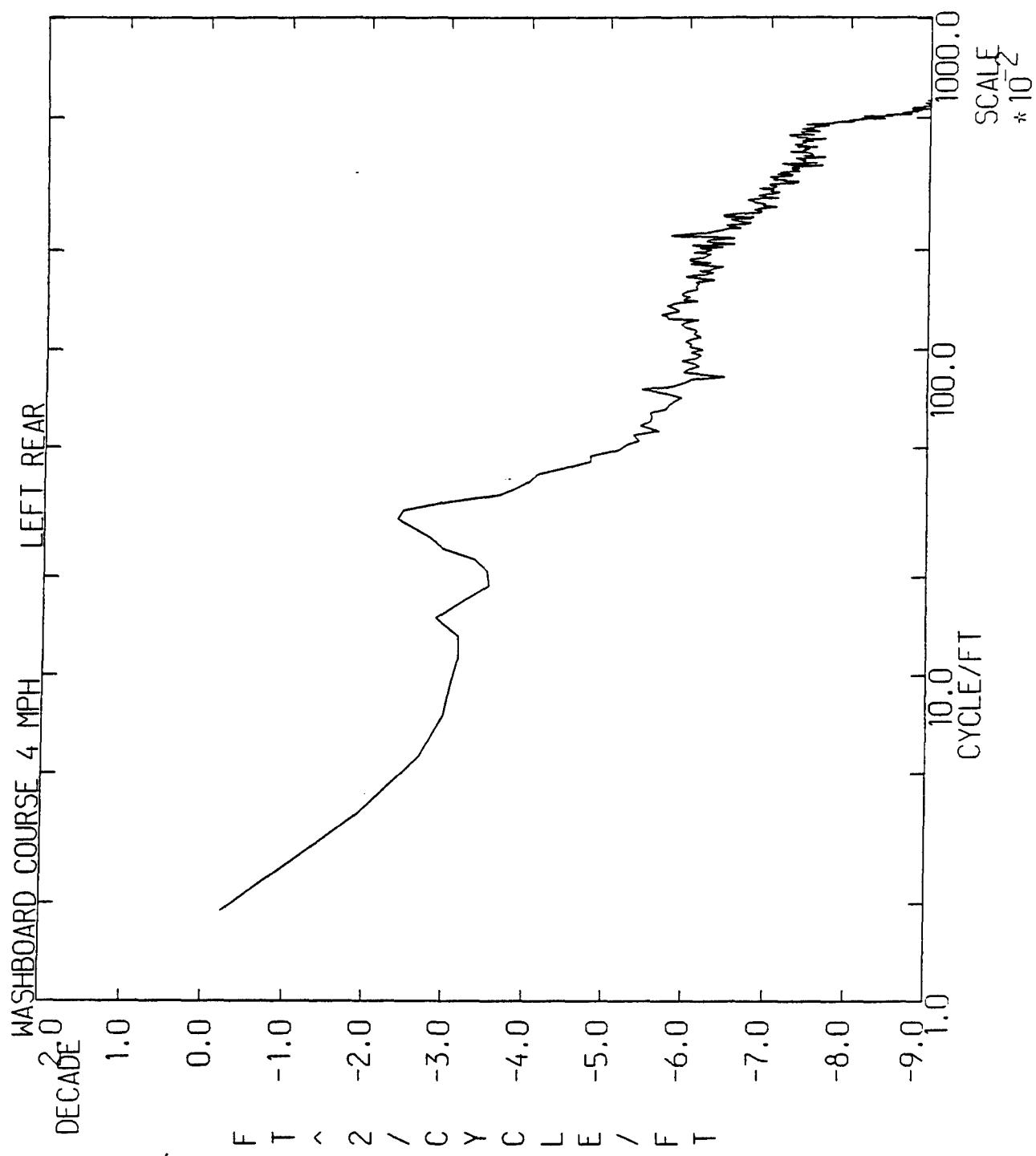




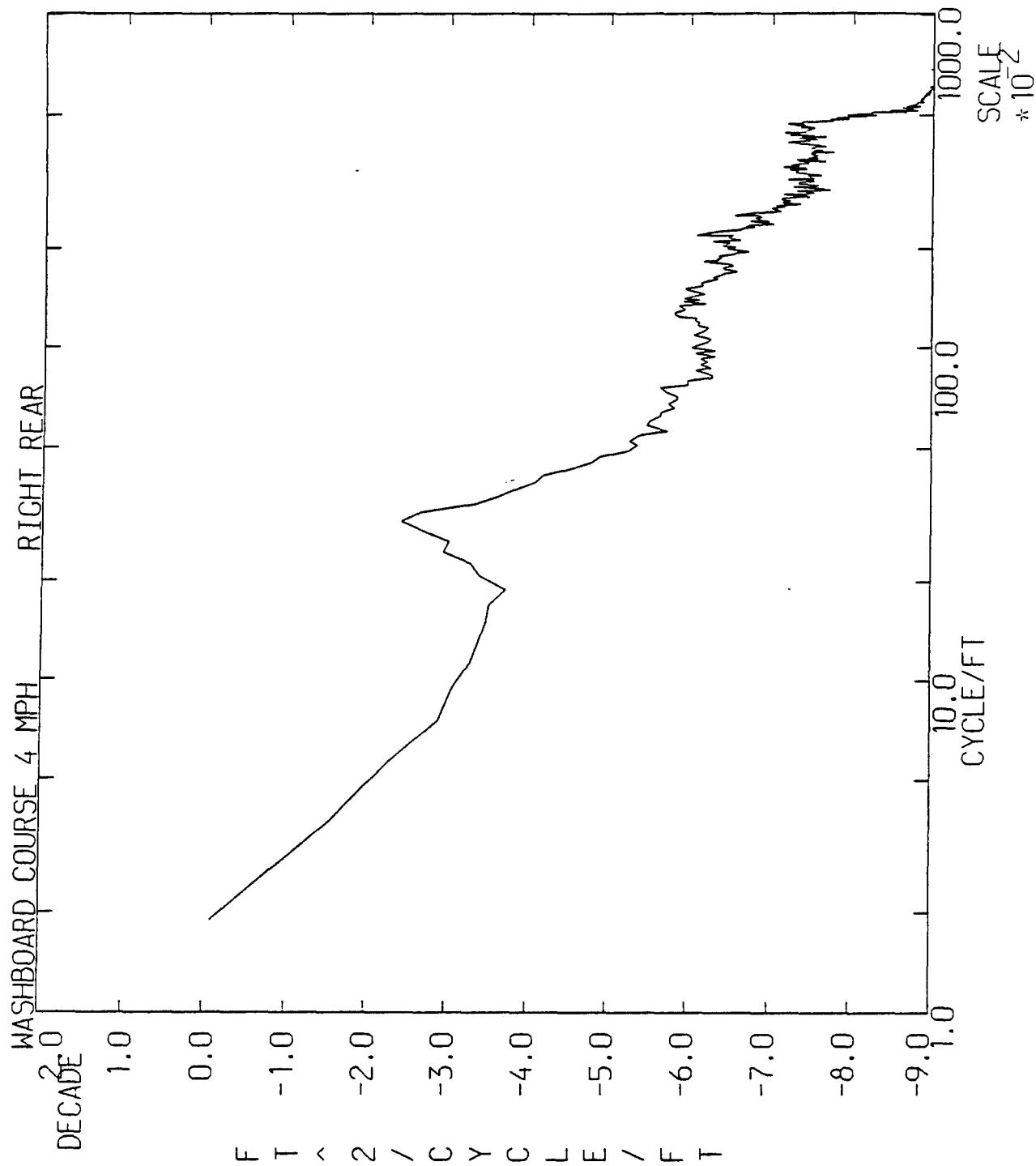


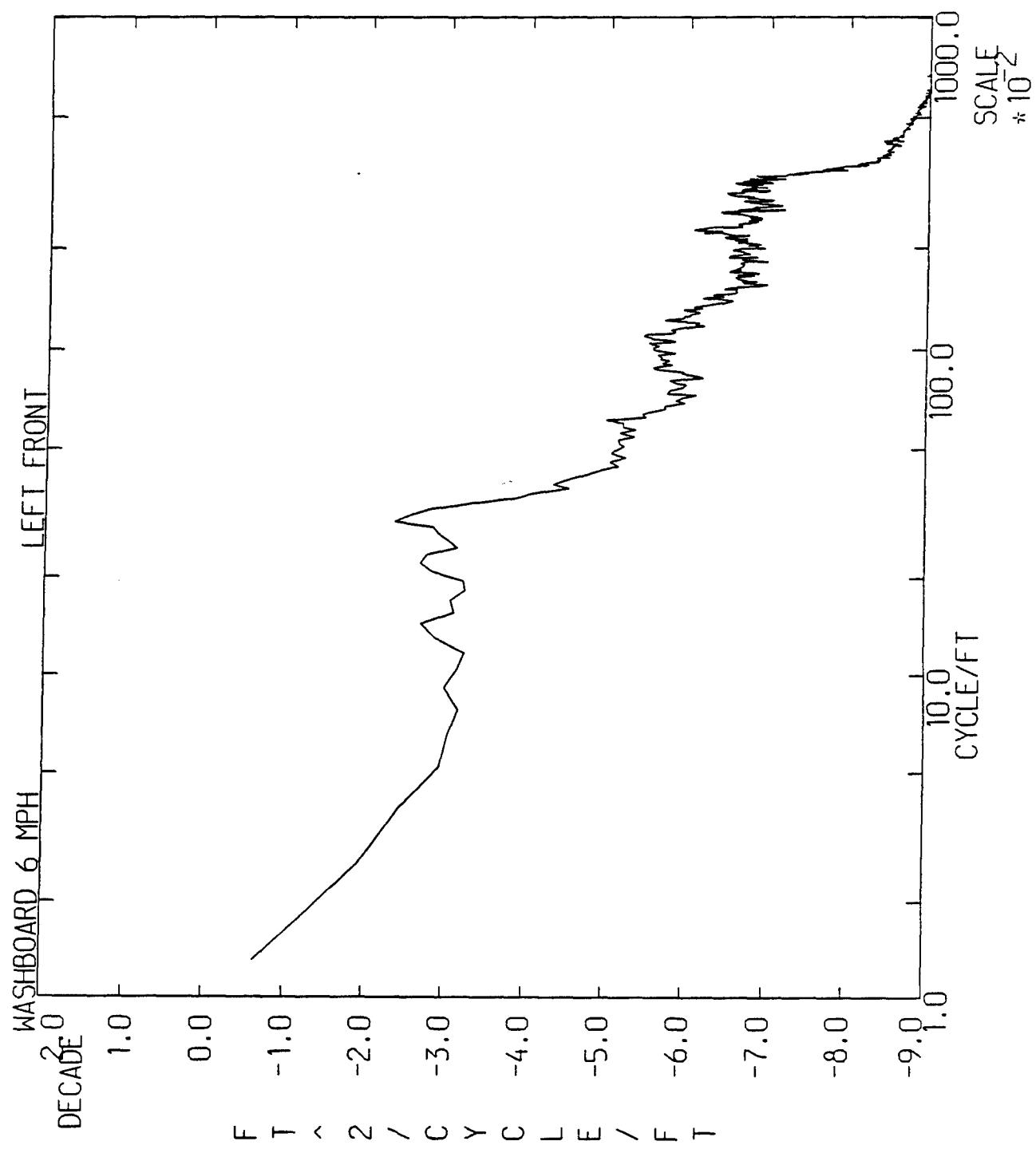


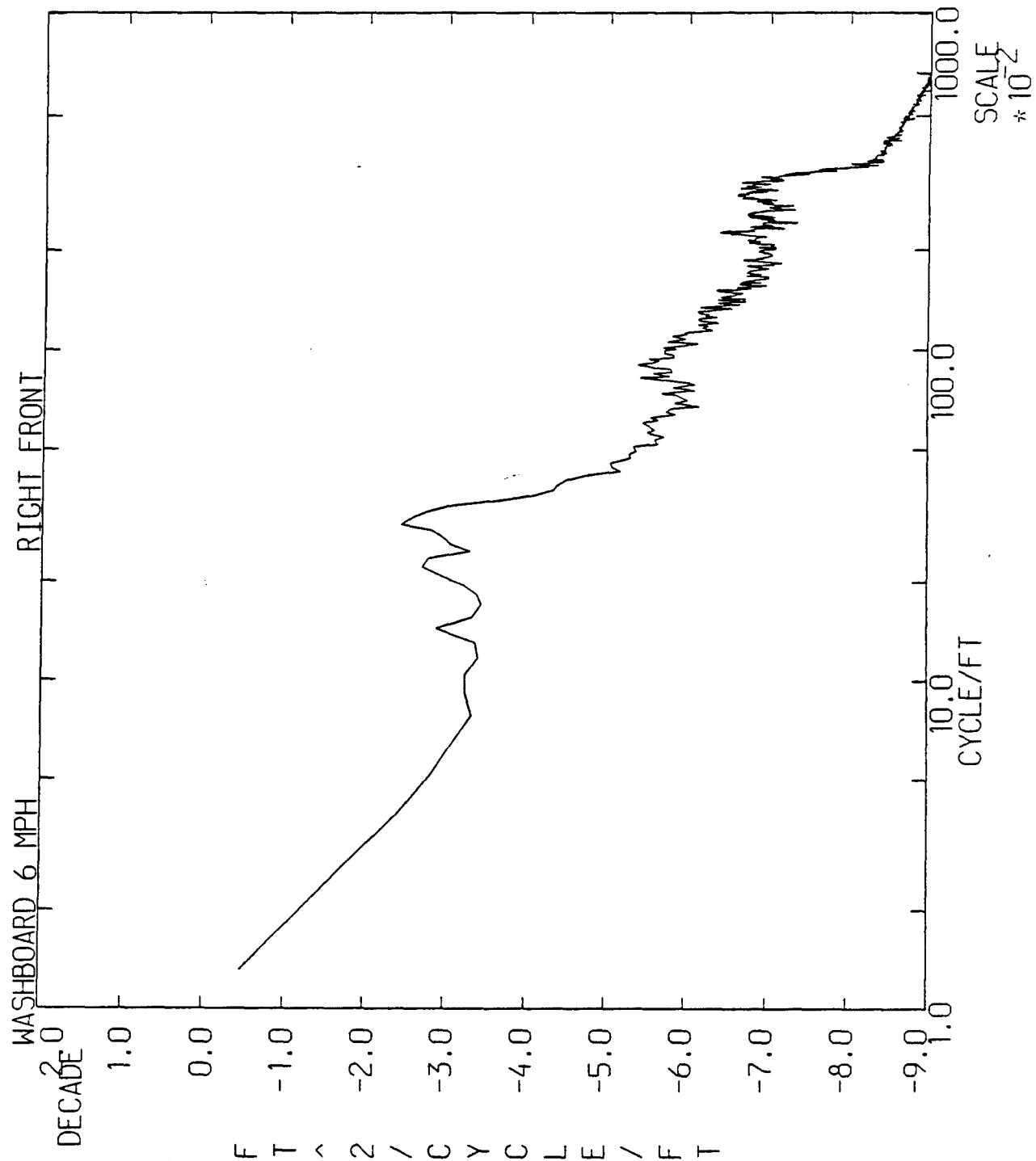


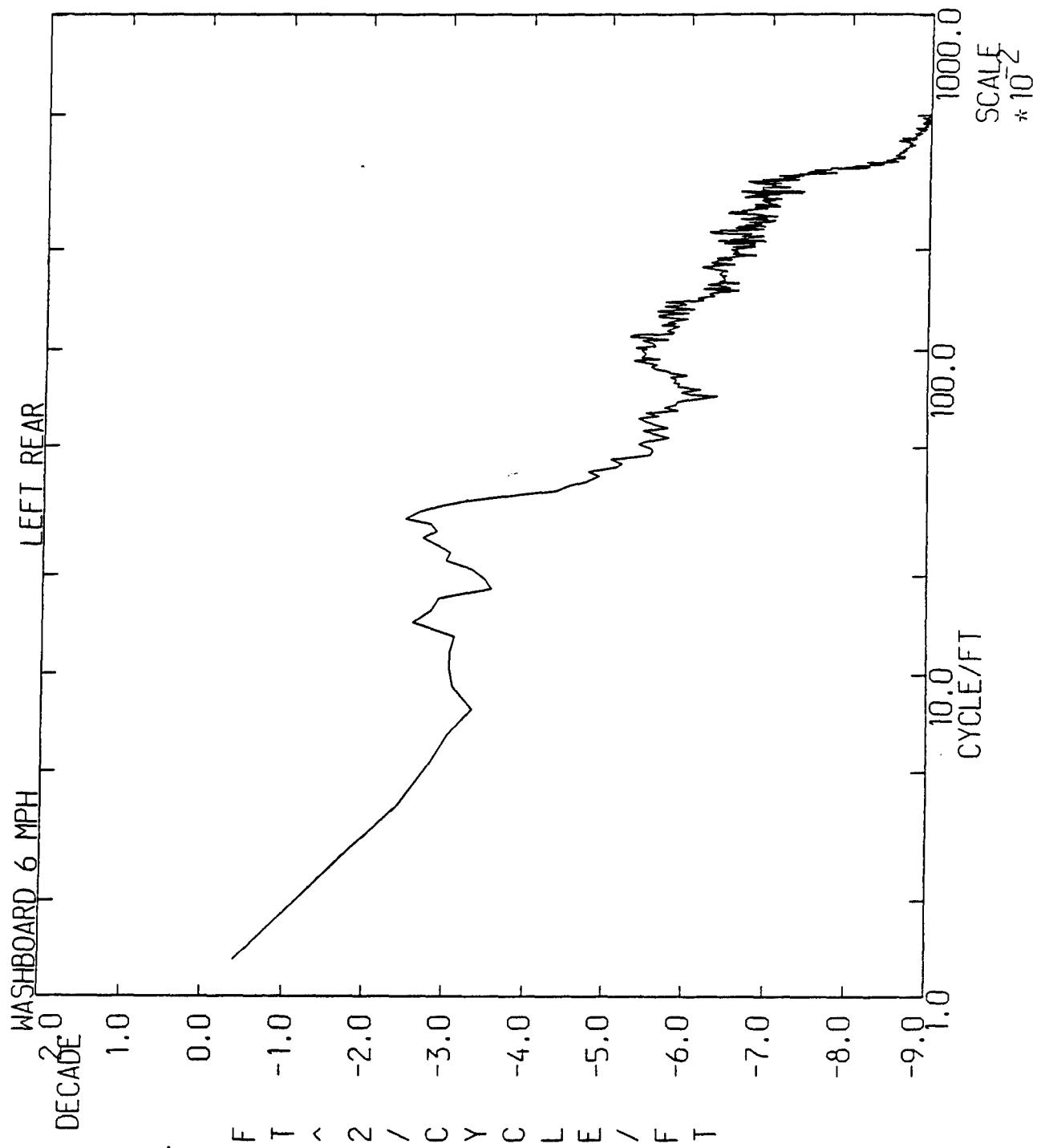


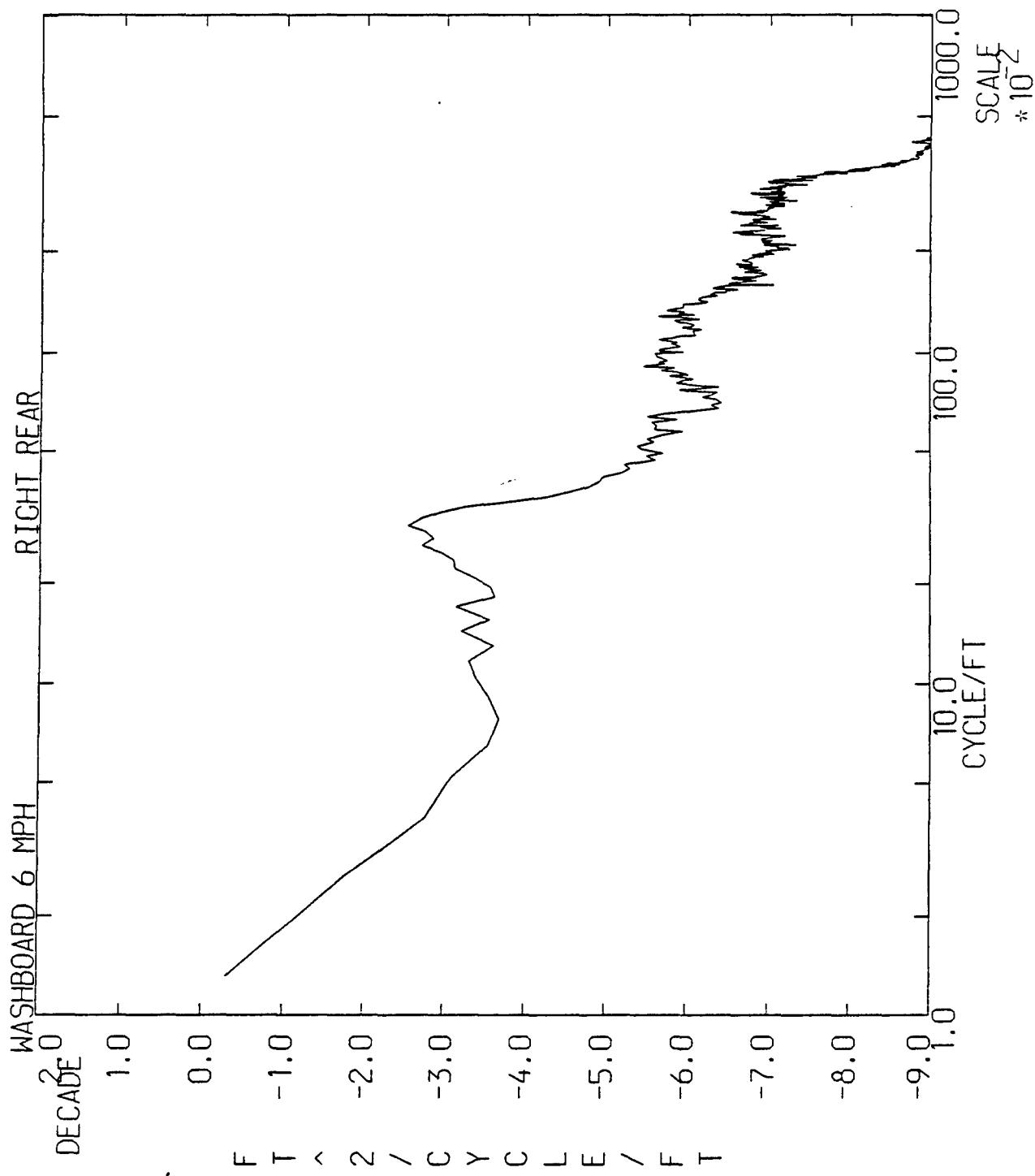
050

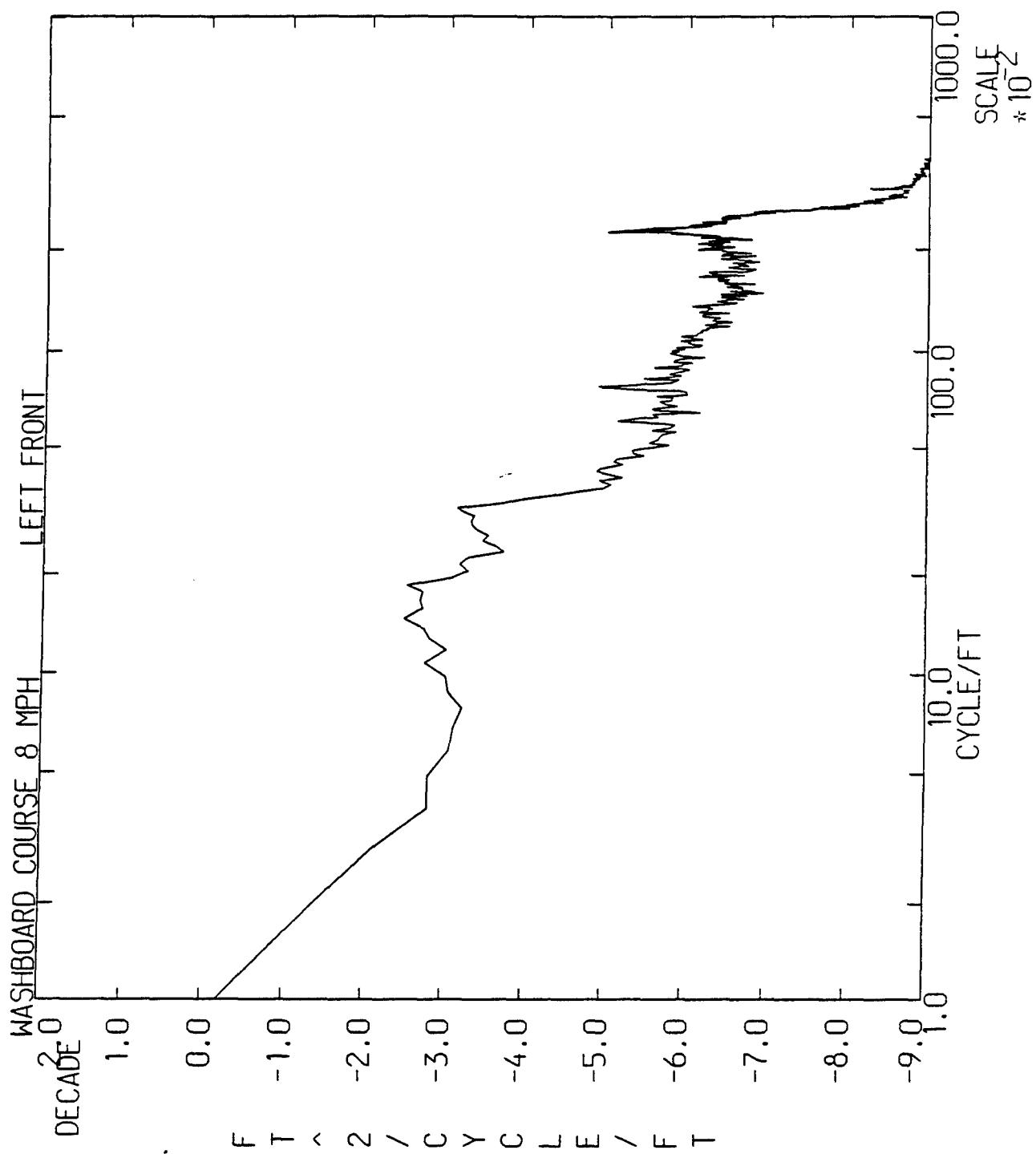


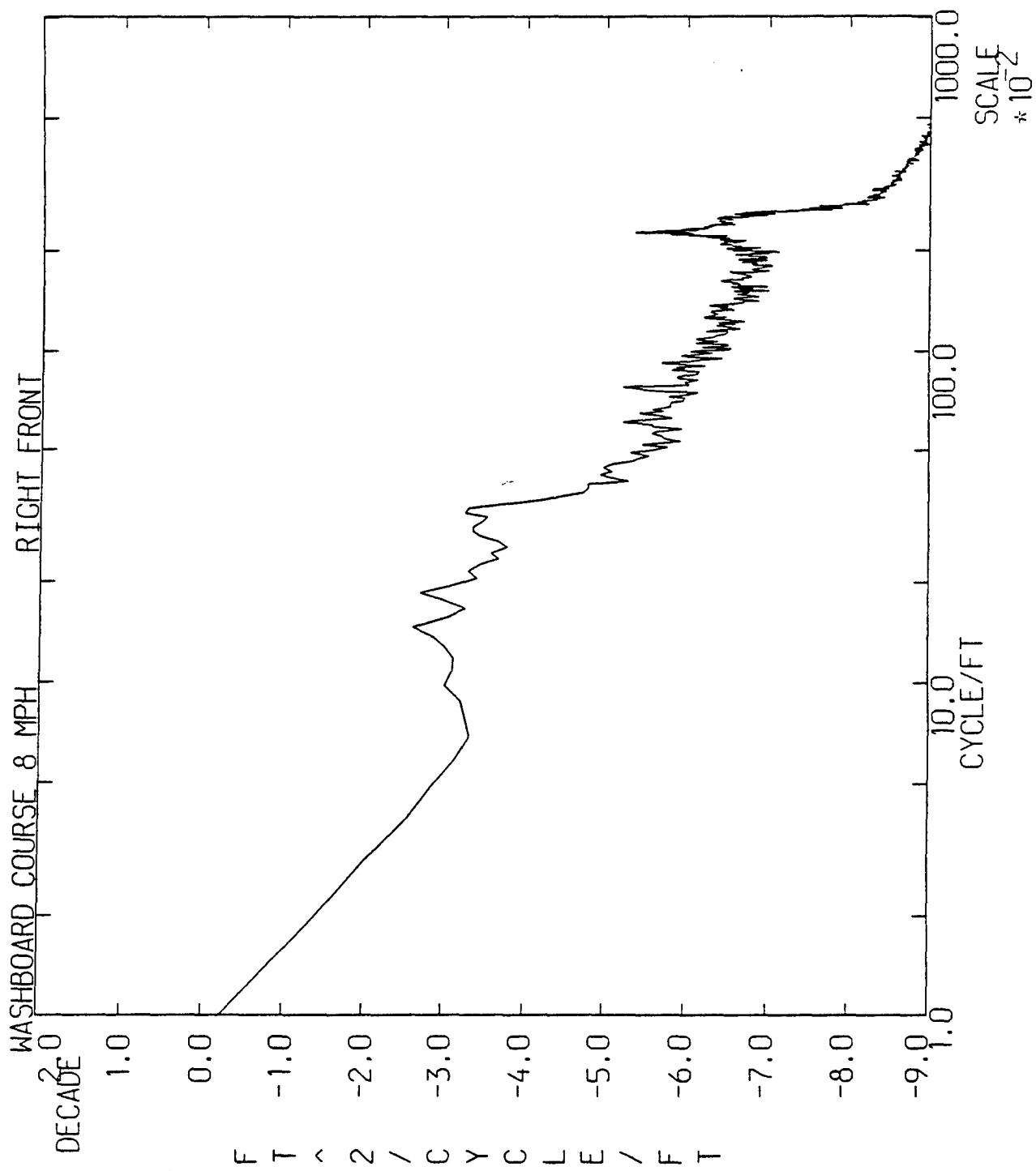


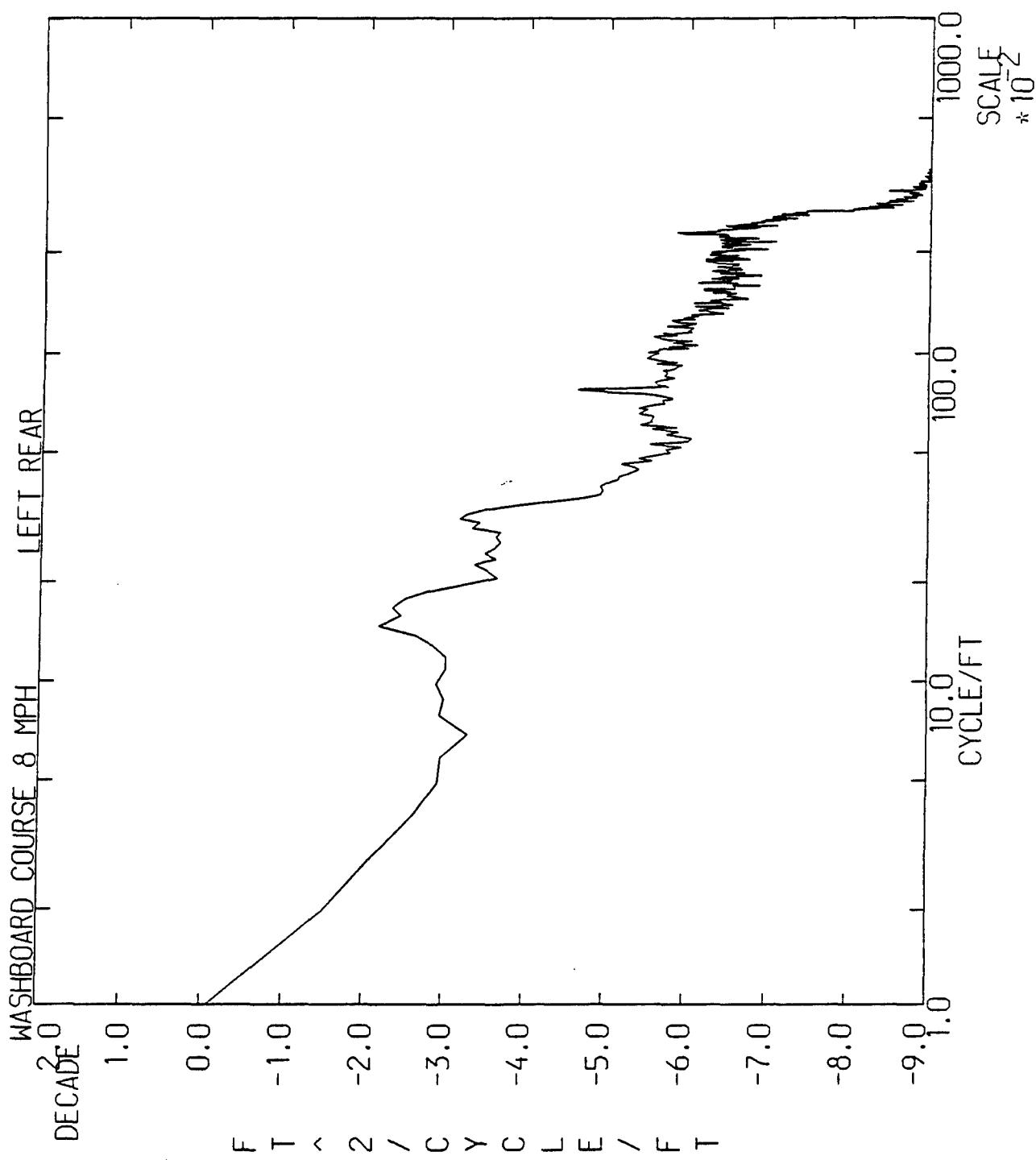


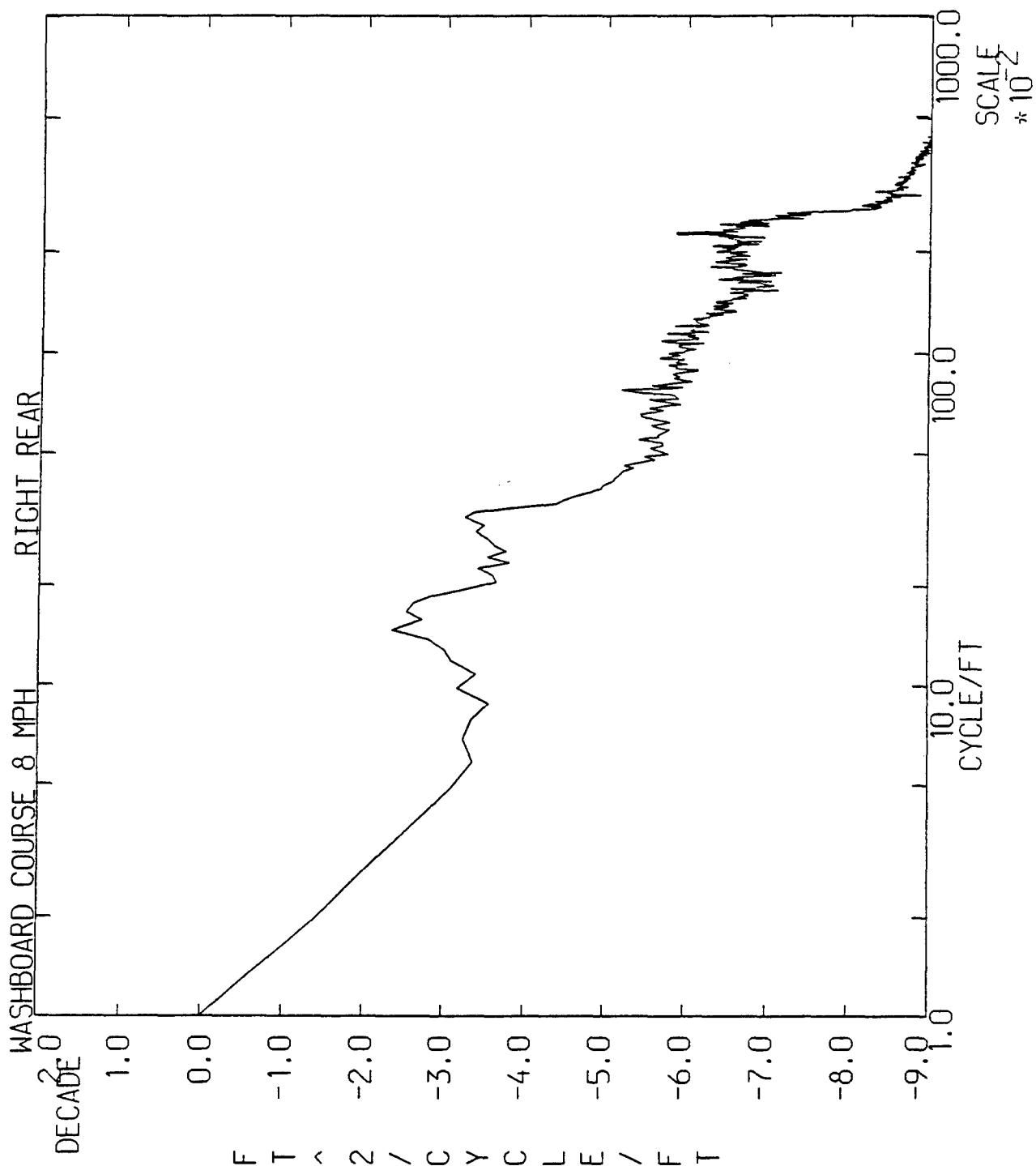




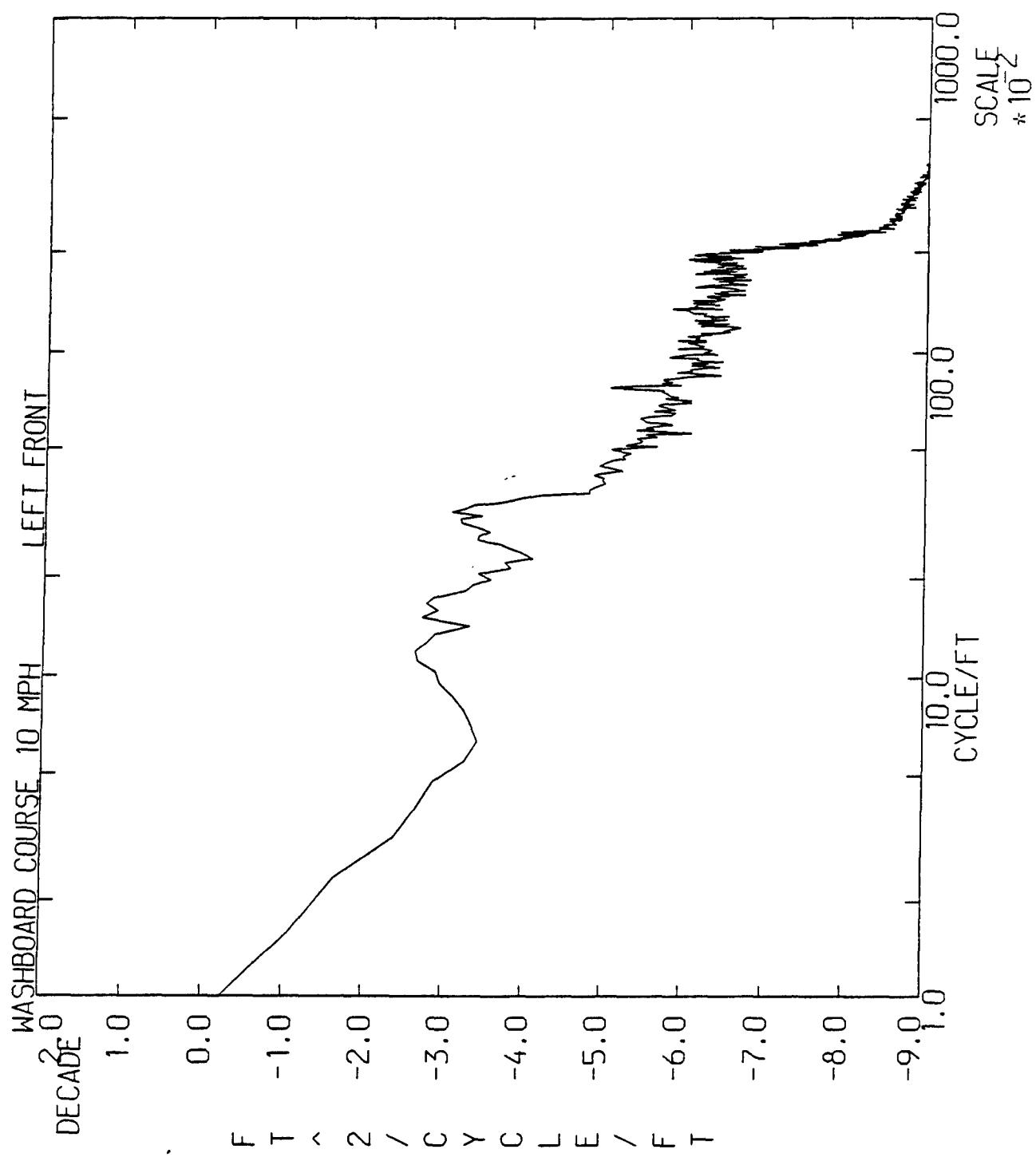


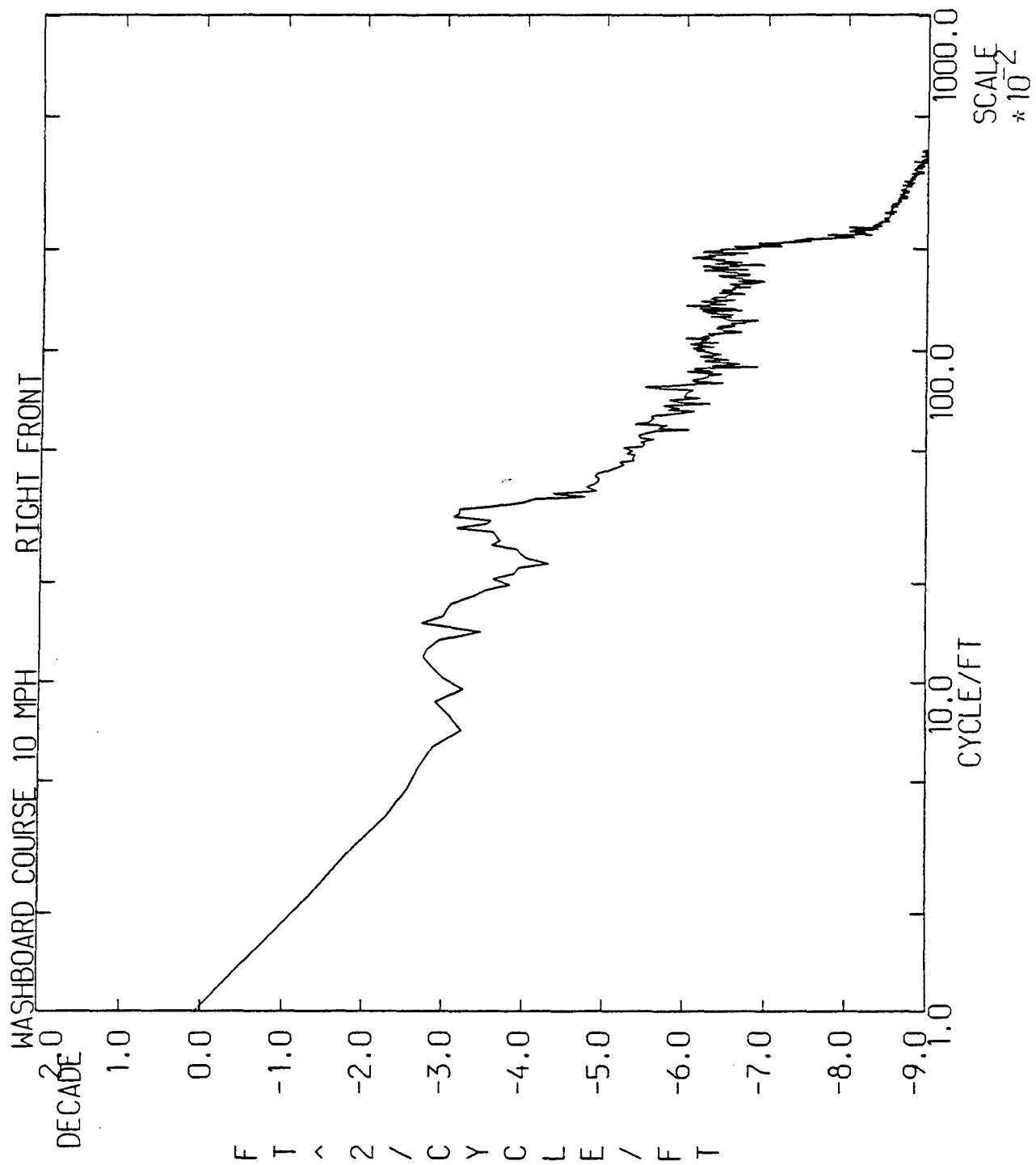


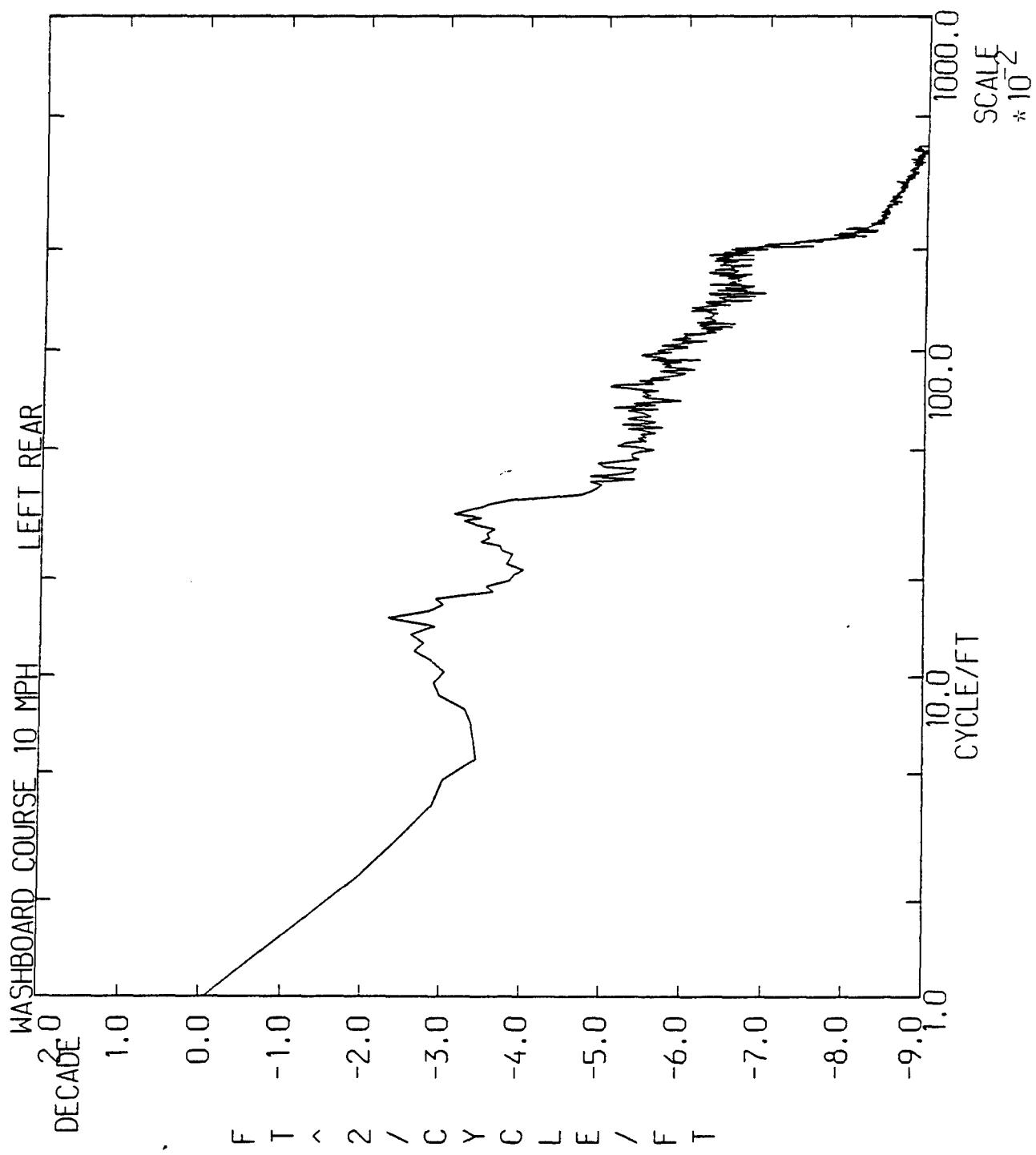


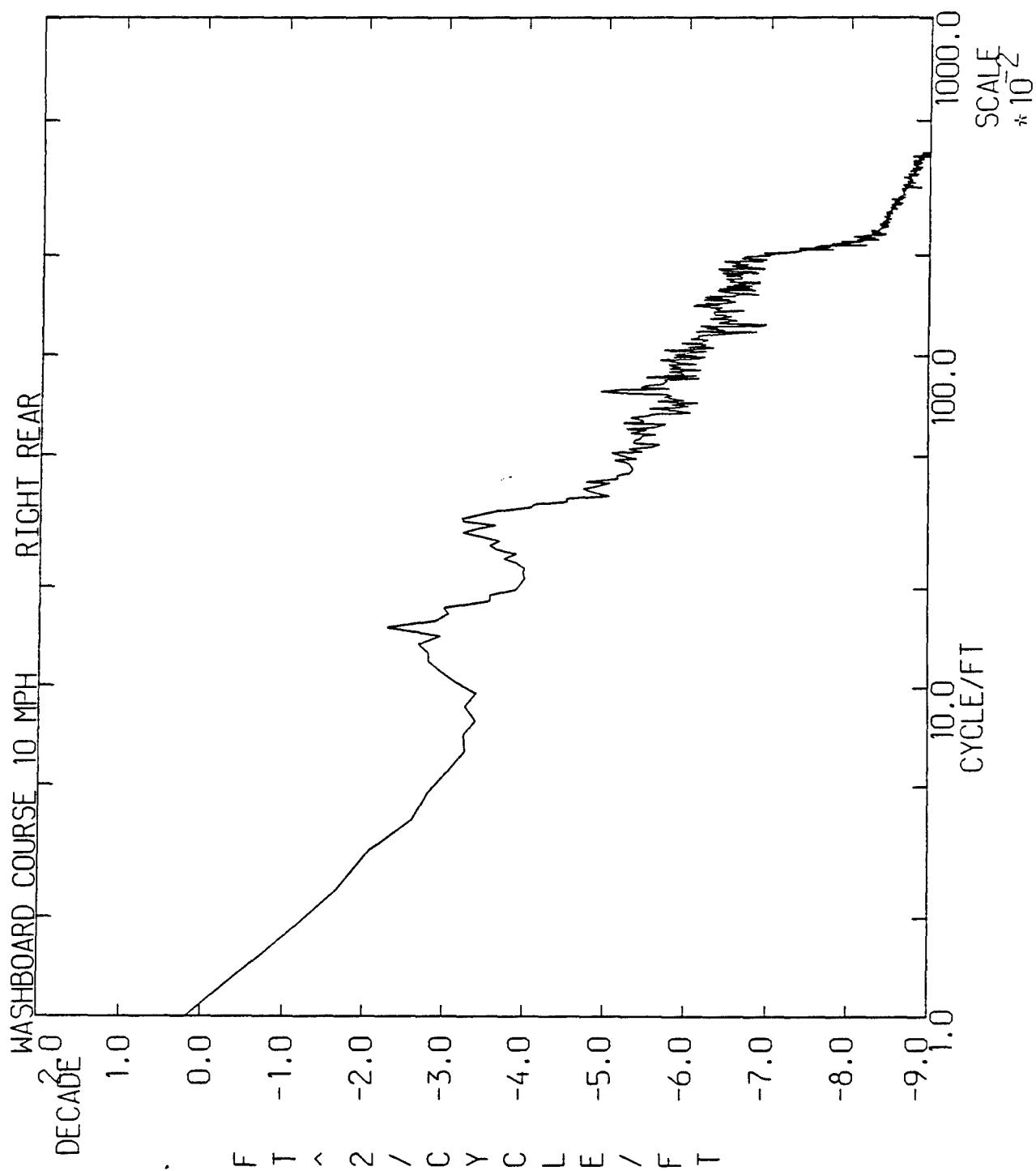


089









MIDDLE EAST #1

WAVE-NUMBER SPECTRA

2, 4, 6, 8 and 10 MPH

Four (4) curves per speed, one for each DFMV tire, as follows

LEFT FRONT
RIGHT FRONT
LEFT REAR
RIGHT REAR

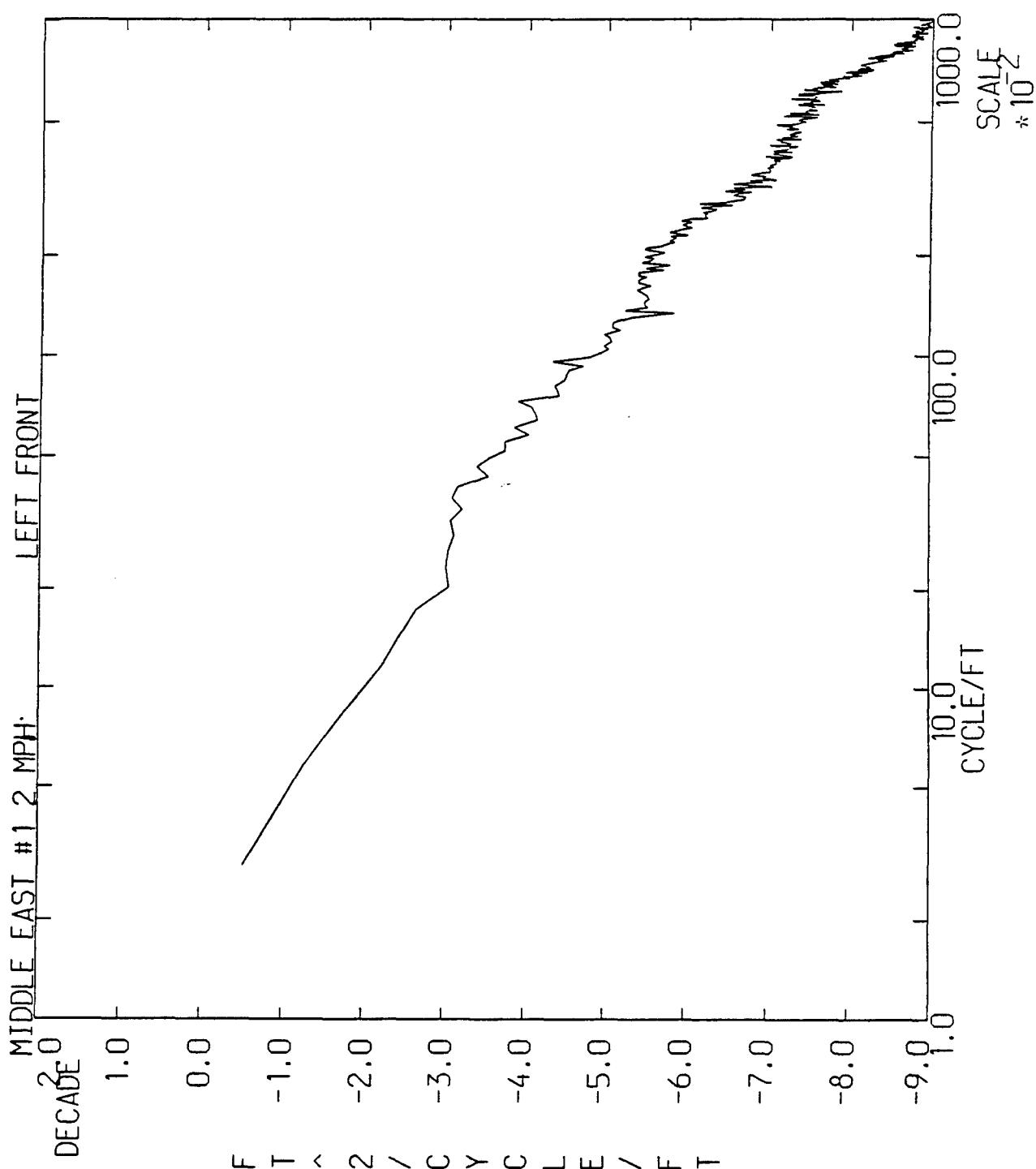
Volume II contains the data for the different DFMV speeds over each YPG course. The data was previously submitted to TACOM in an interim data report, however, the data was not reprocessed with the signal processing considerations discussed in the Volume I report (e.g., in this data, much of the spectral resolution was below the footprint). The wave-number cut-off at the low end of the spectra was limited by the frequency range of the accelerometer, as discussed in the report and shown in the table below. The wave-number cut-off at the high end of the spectrum was limited by the footprint length of the DFMV tire, which was $\approx 1.2 \text{ ft}^{-1}$. These cut-offs were verified through the DFMV front-to-rear coherence plots. Therefore, when comparing plots between different speeds, do not compare the data past these limits. As discussed in the report, the faster speed runs produced the best results at the lower wave numbers.

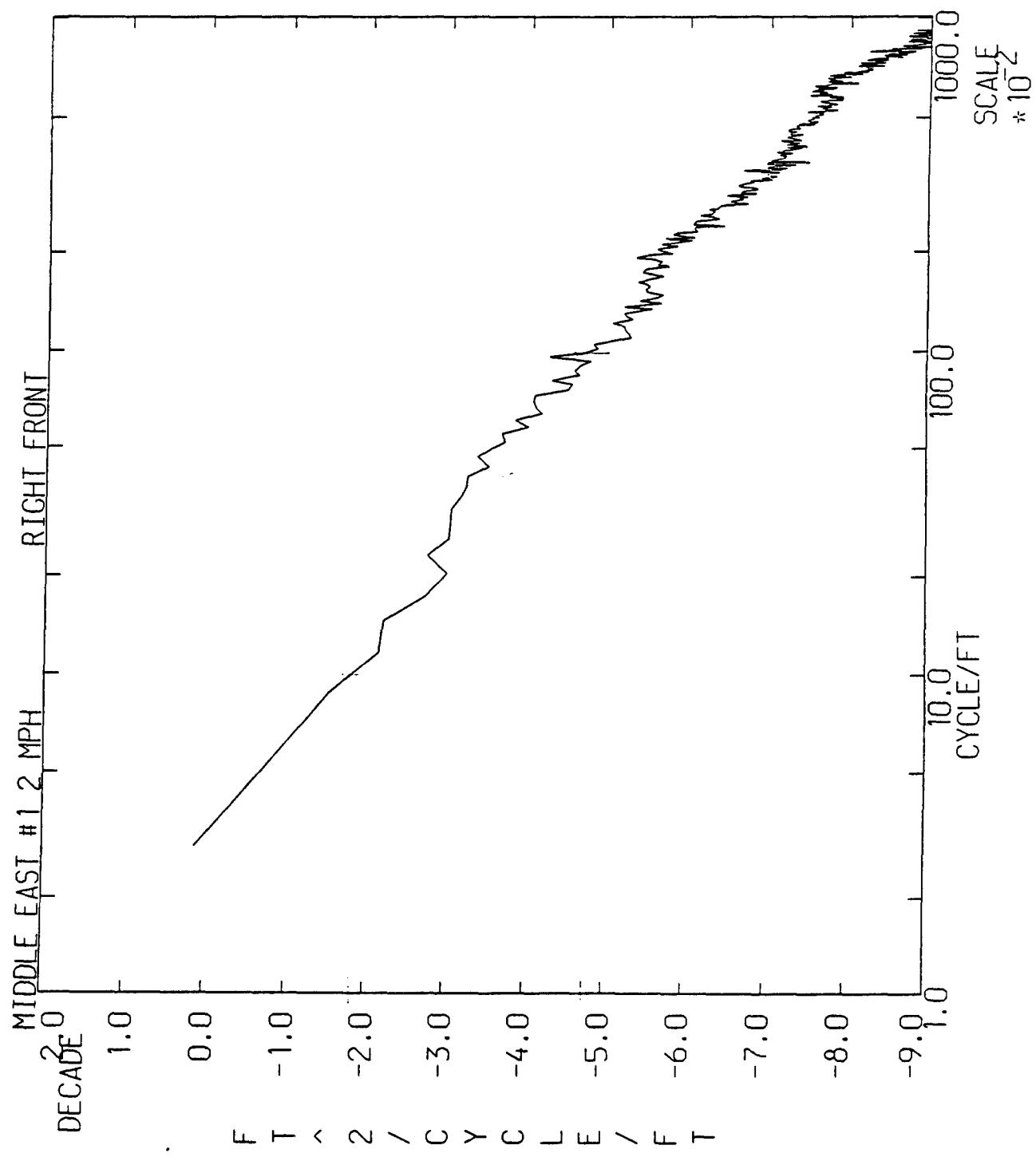
Table 1. DFMV Actual Versus Predicted Wavelength Limits

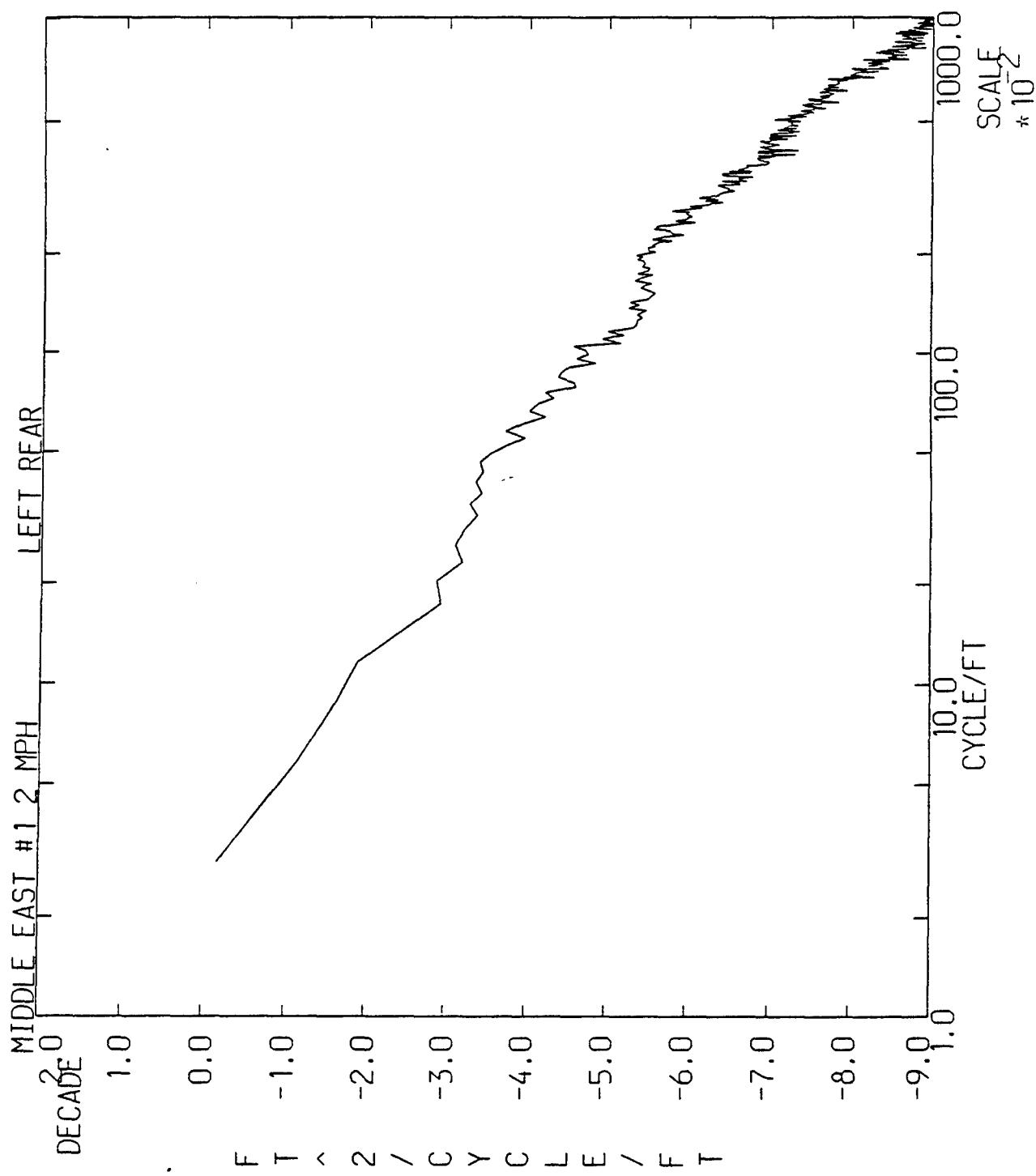
DFMV Speed MPH	Expected Wavelength Resolution*	Actual Wavelength Resolution**
2	60	15
4	120	30
6	180	45
8	240	60
10	300	75

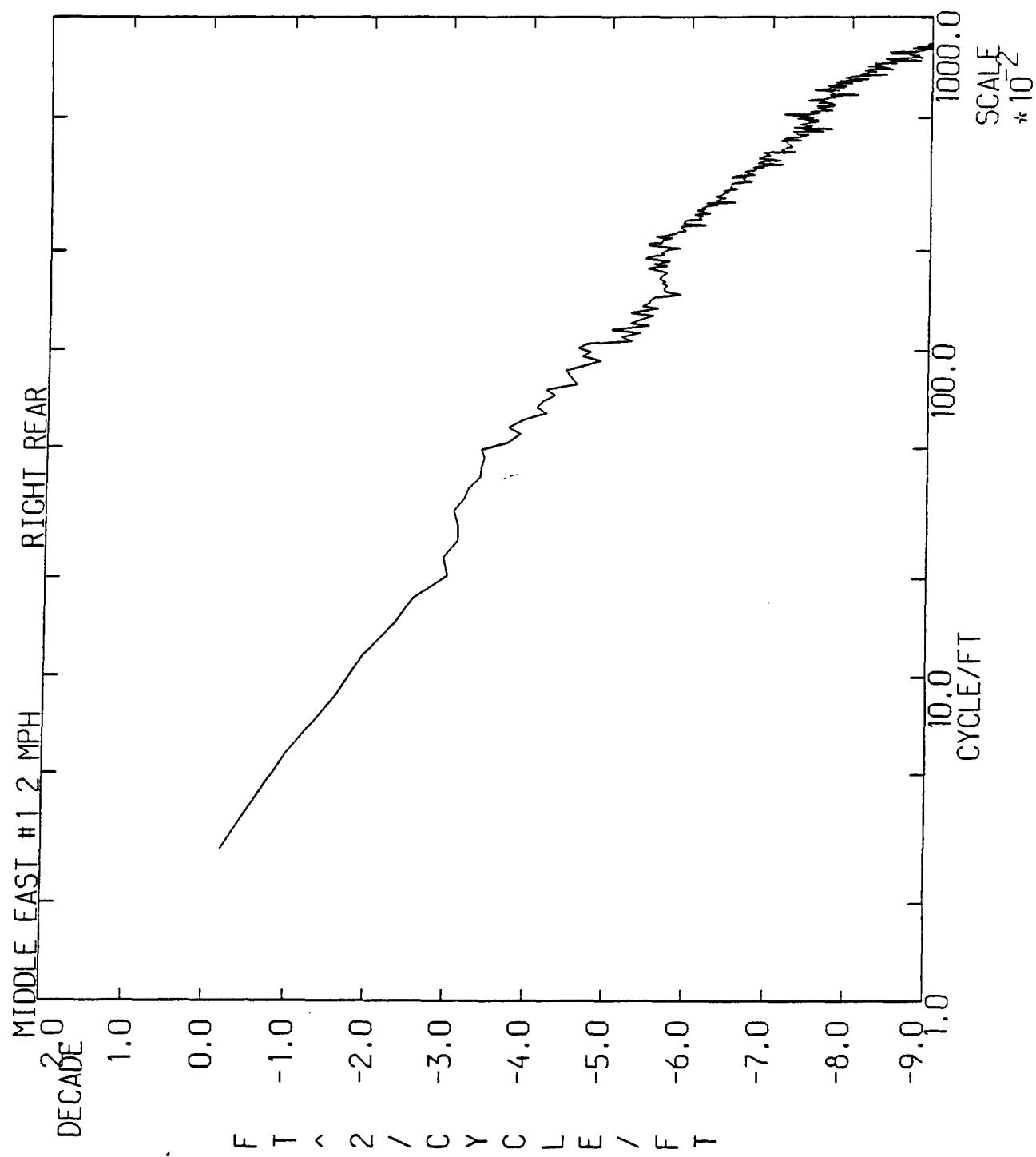
* Based on the advertised low-end frequency range for the accelerometer used

** Based on actual low-end frequency range for the accelerometer used

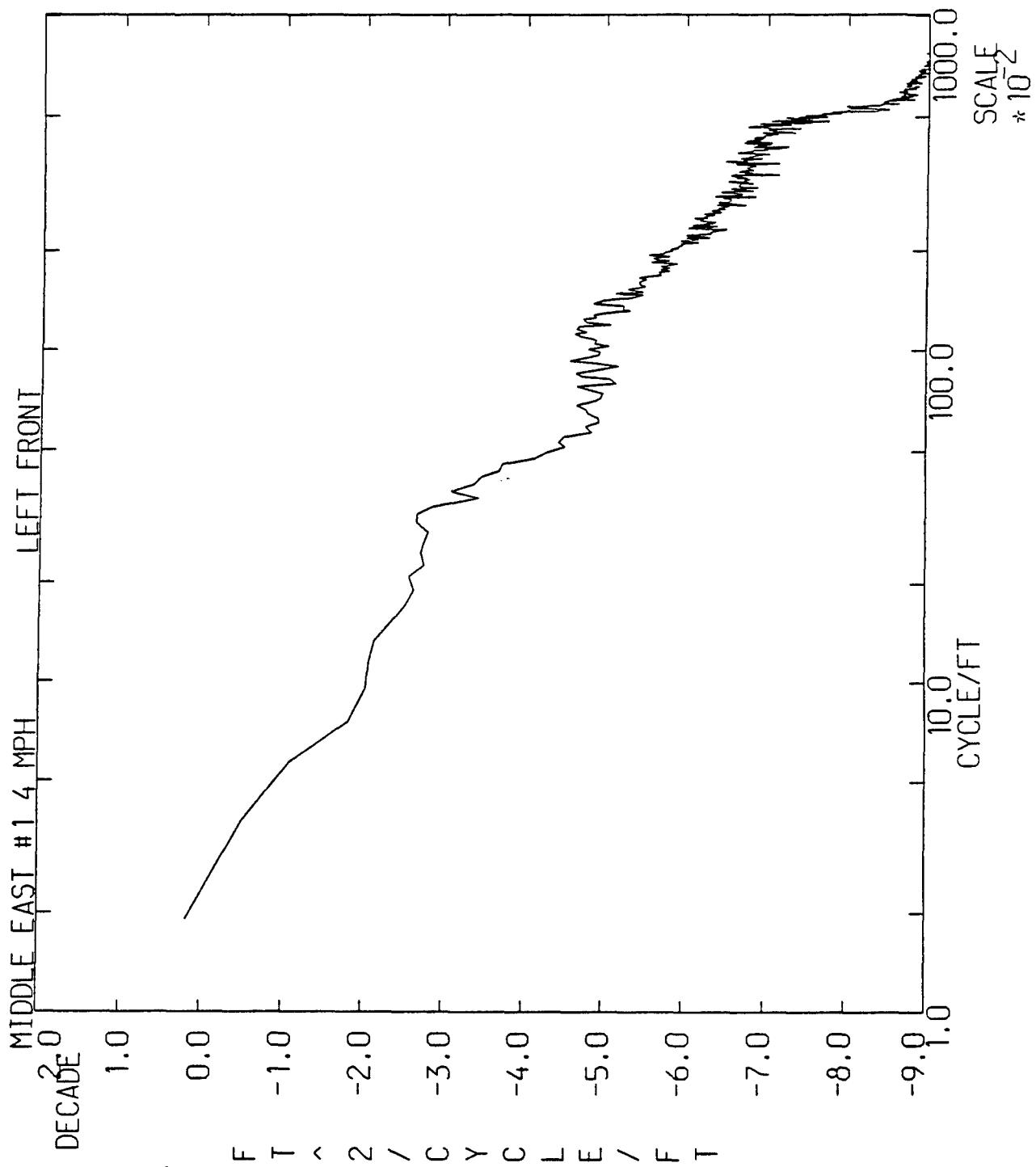




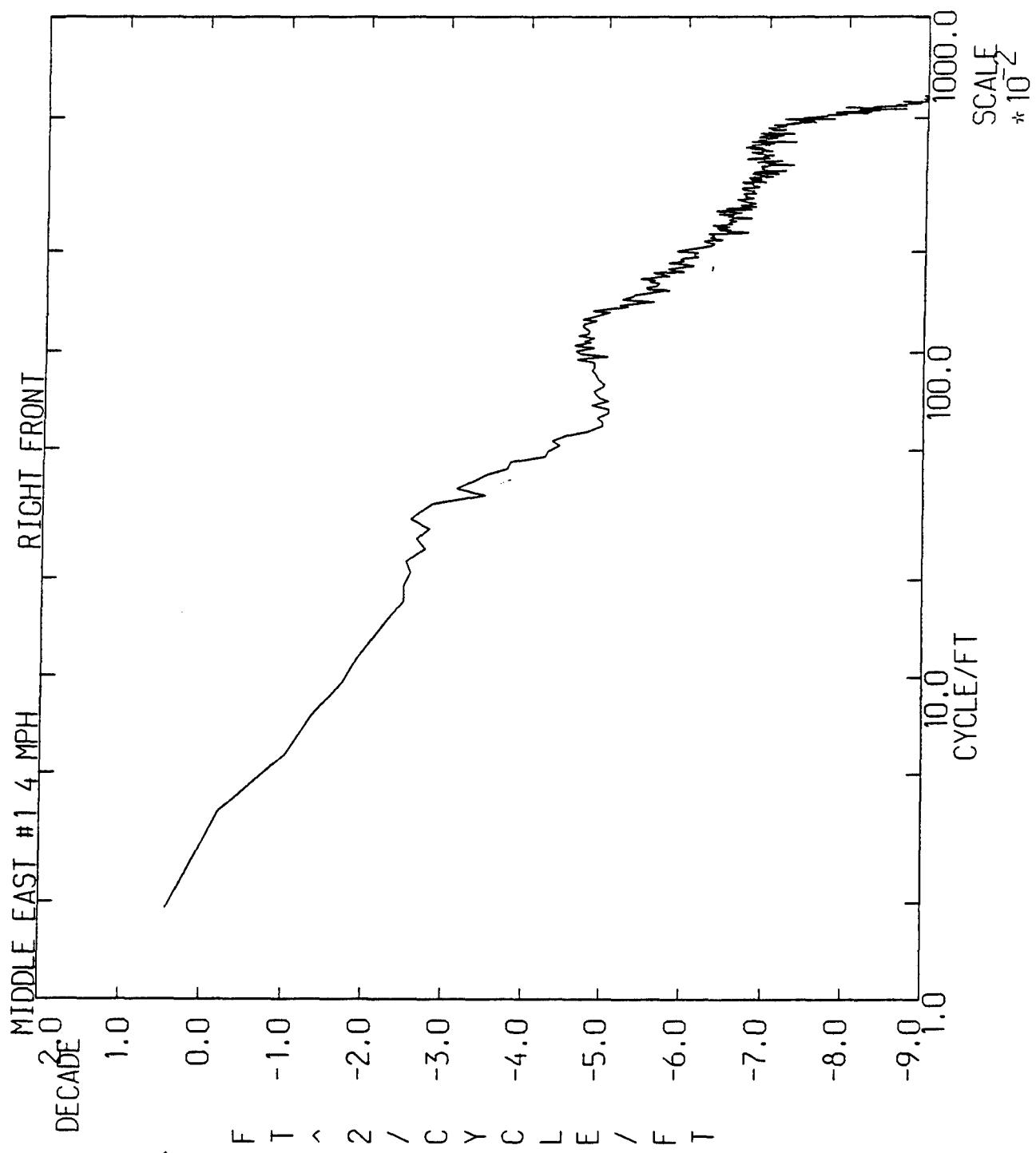


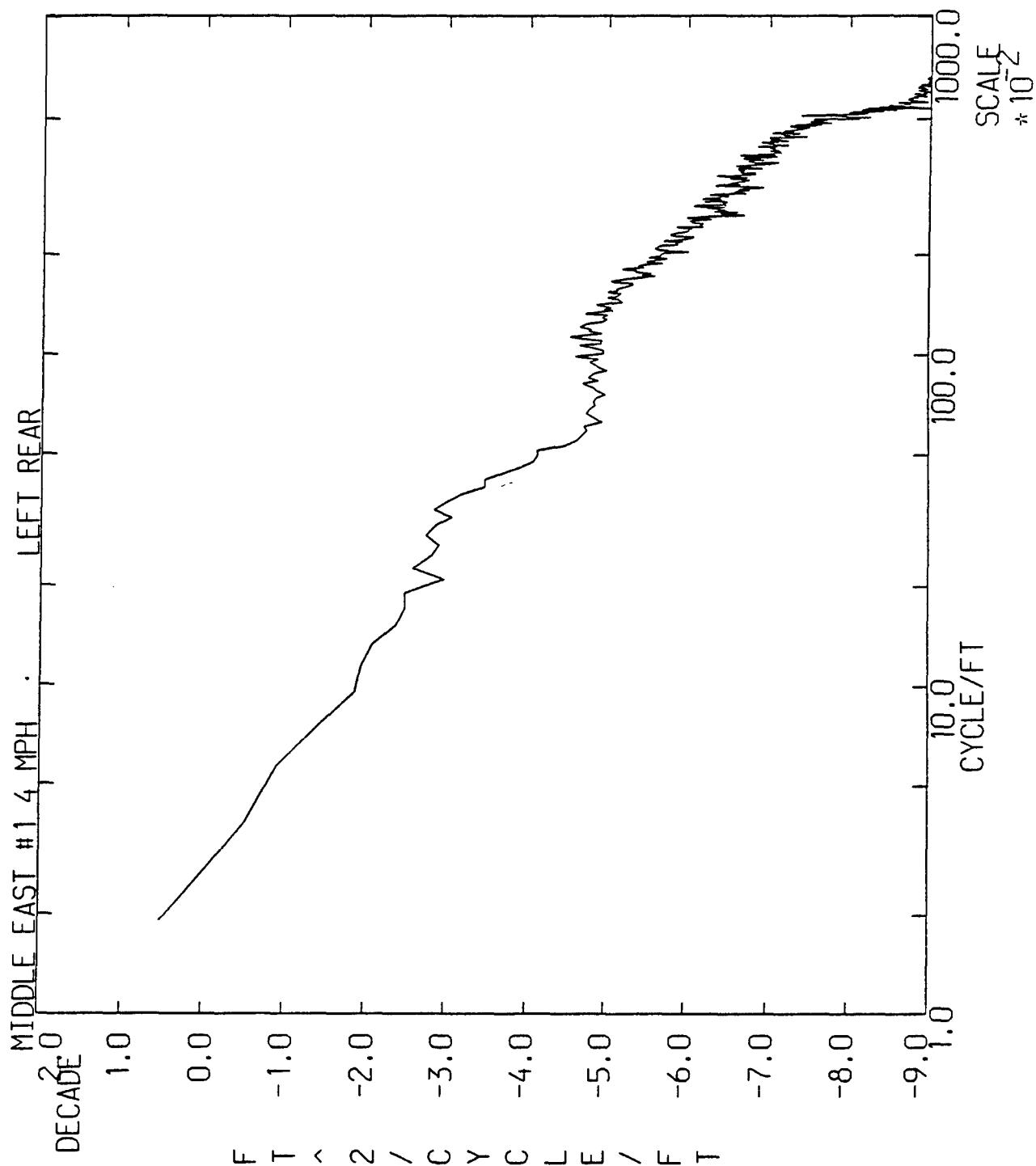


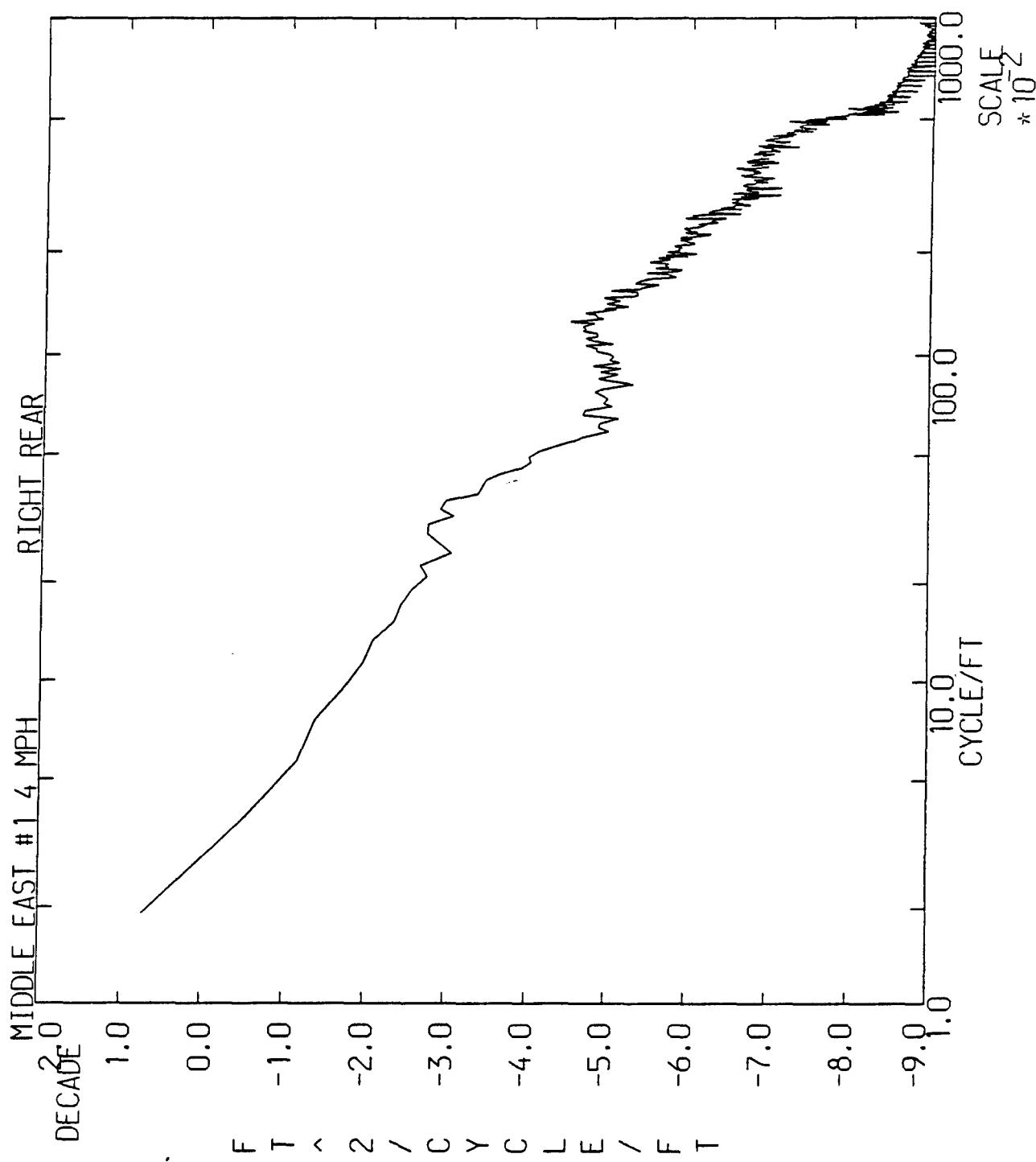
093

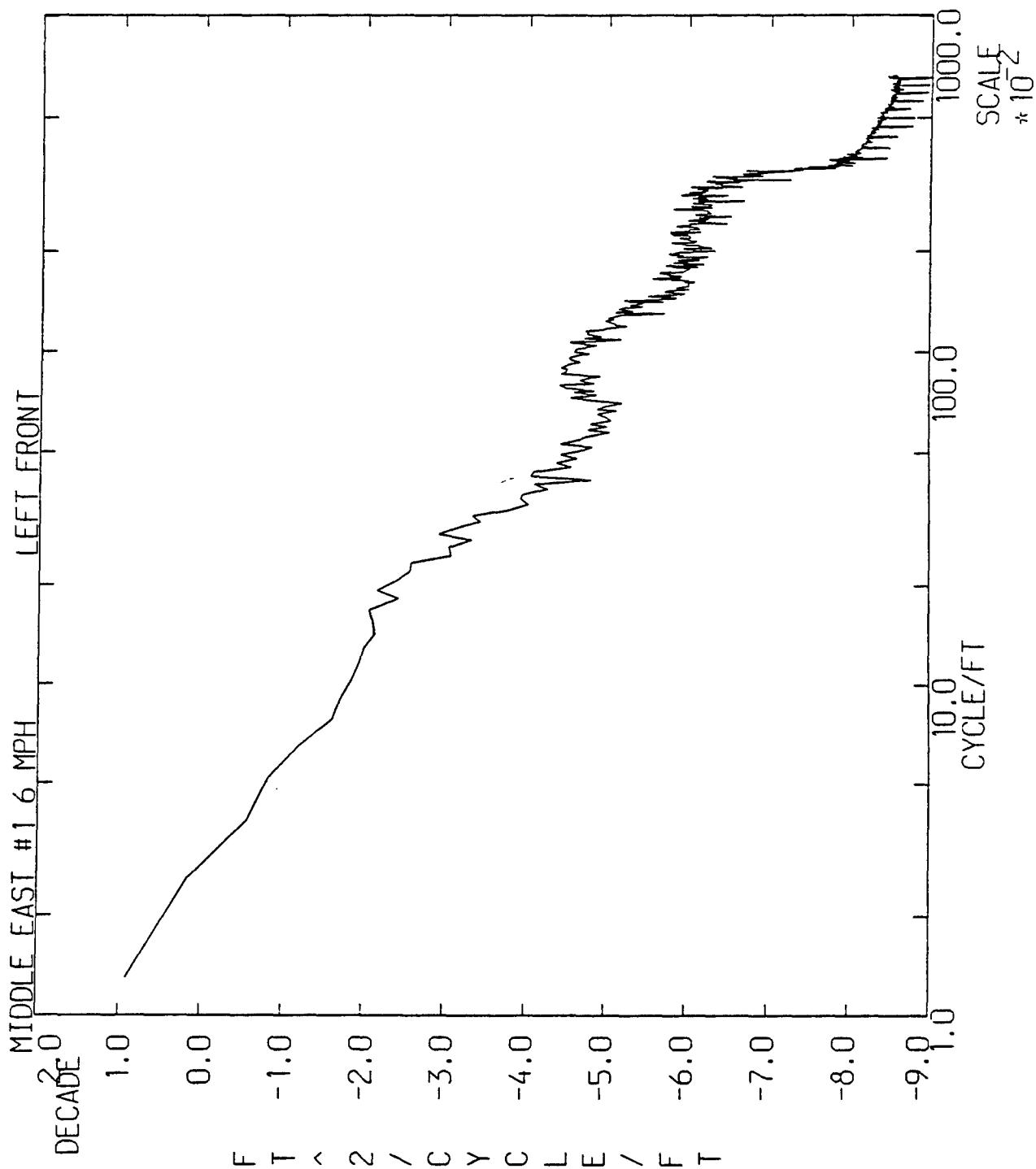


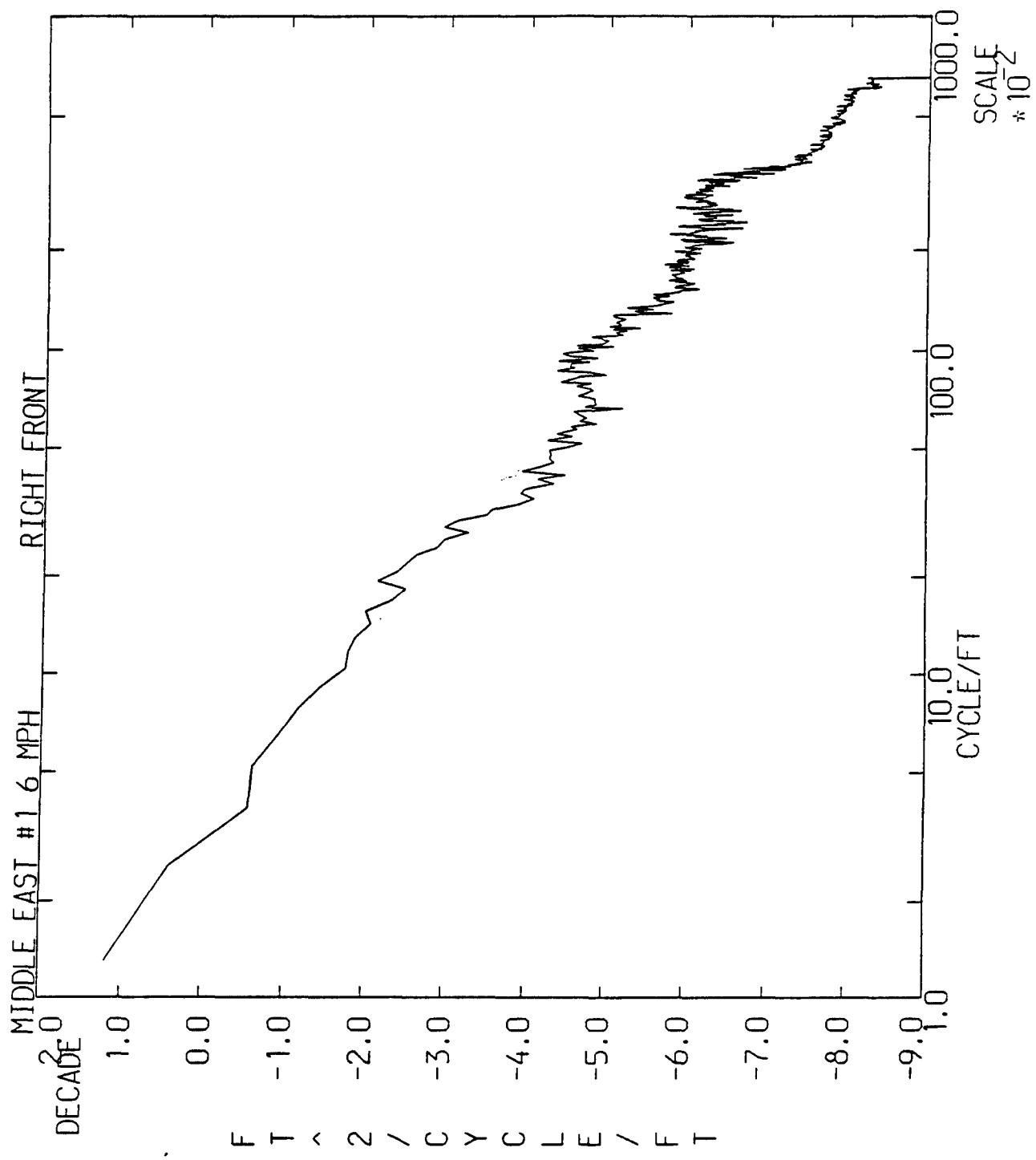
093

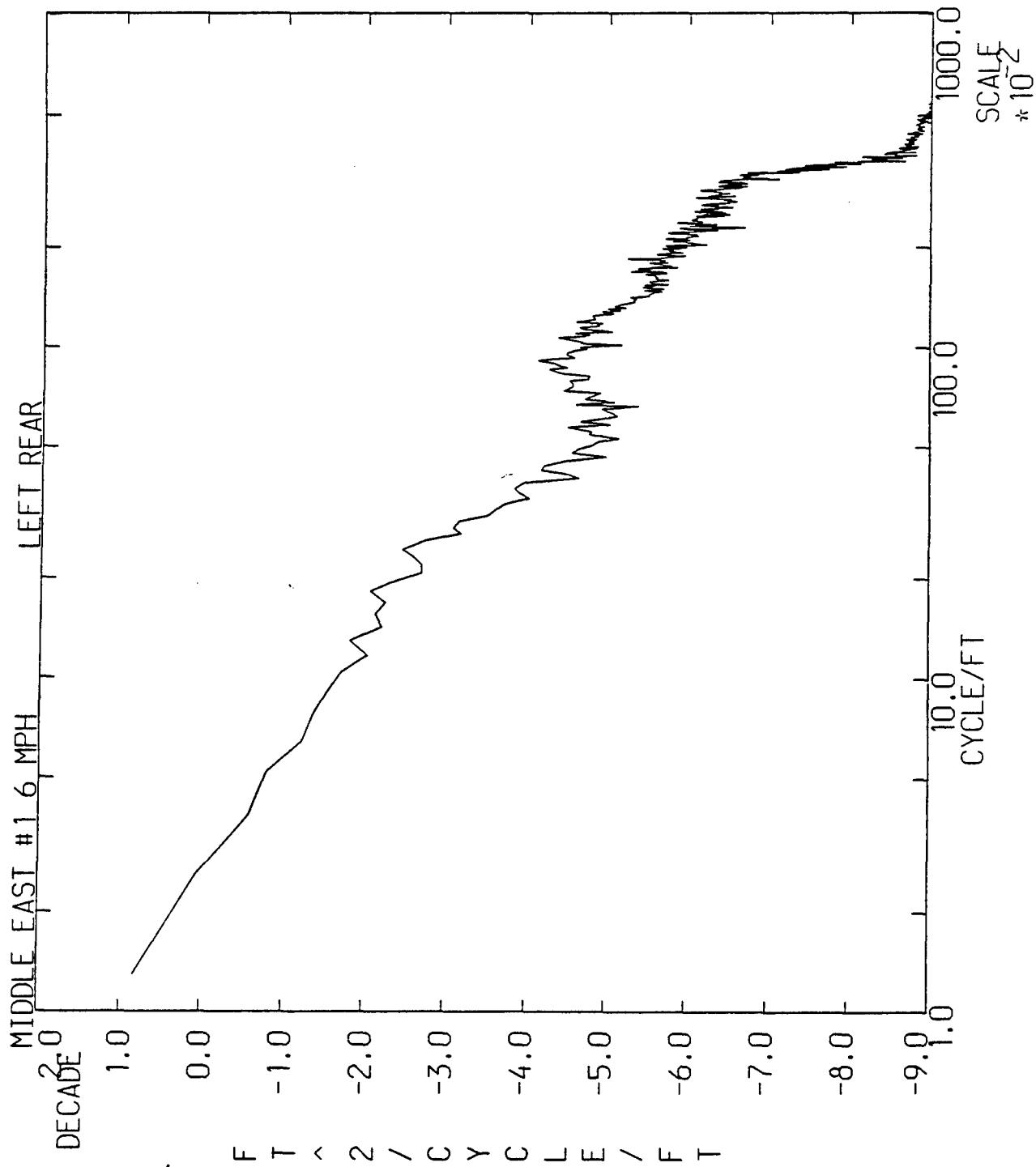


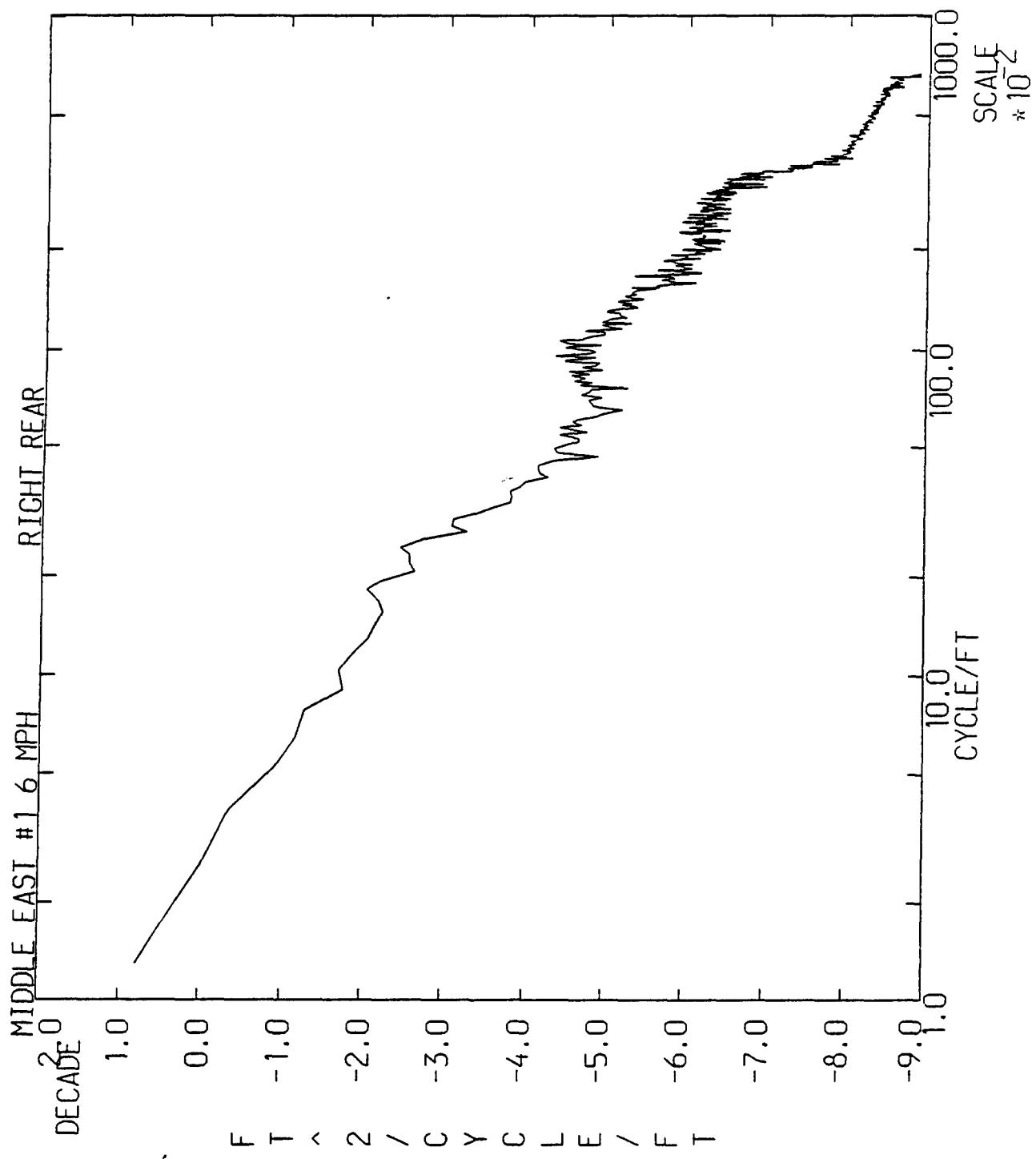


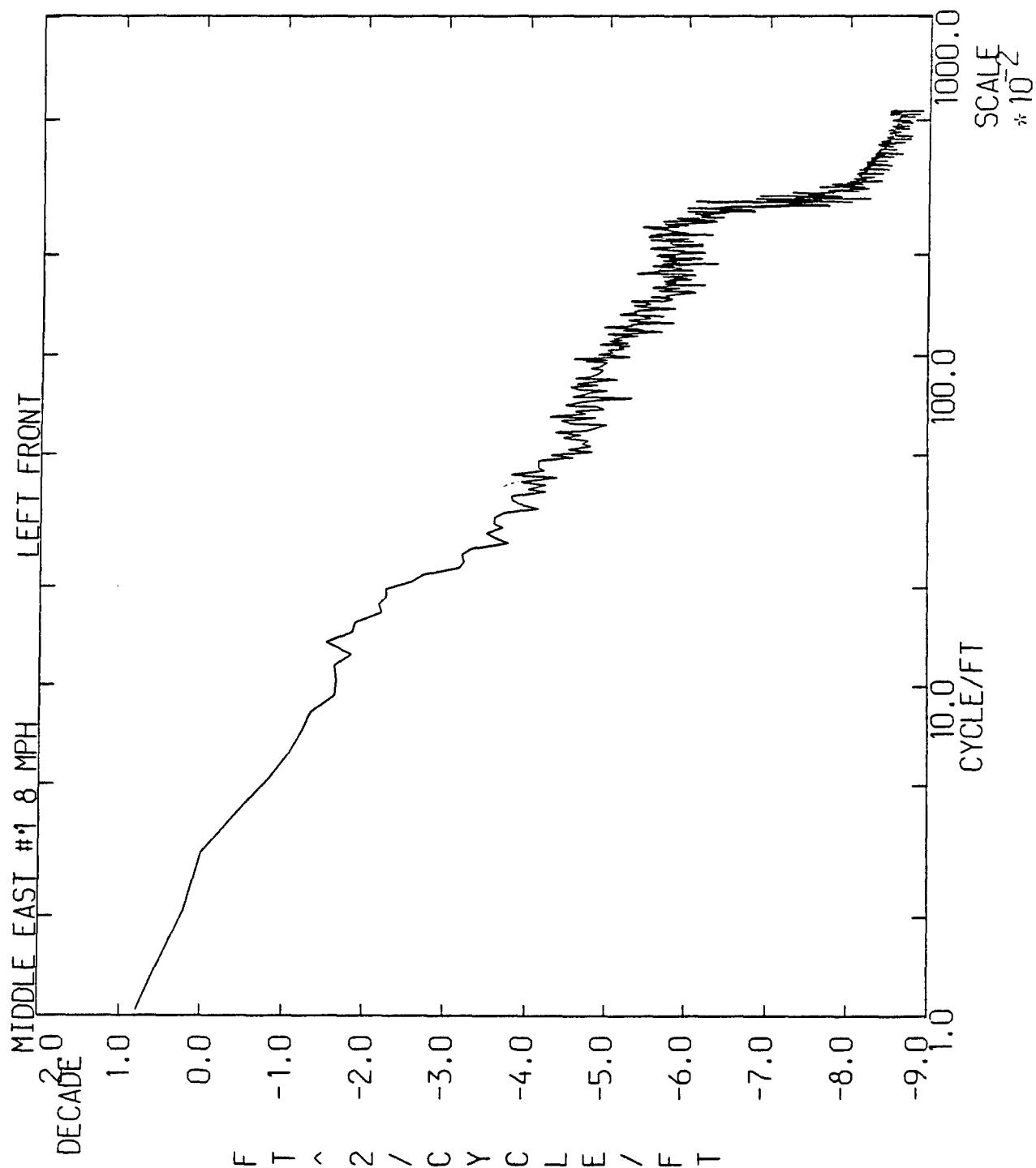


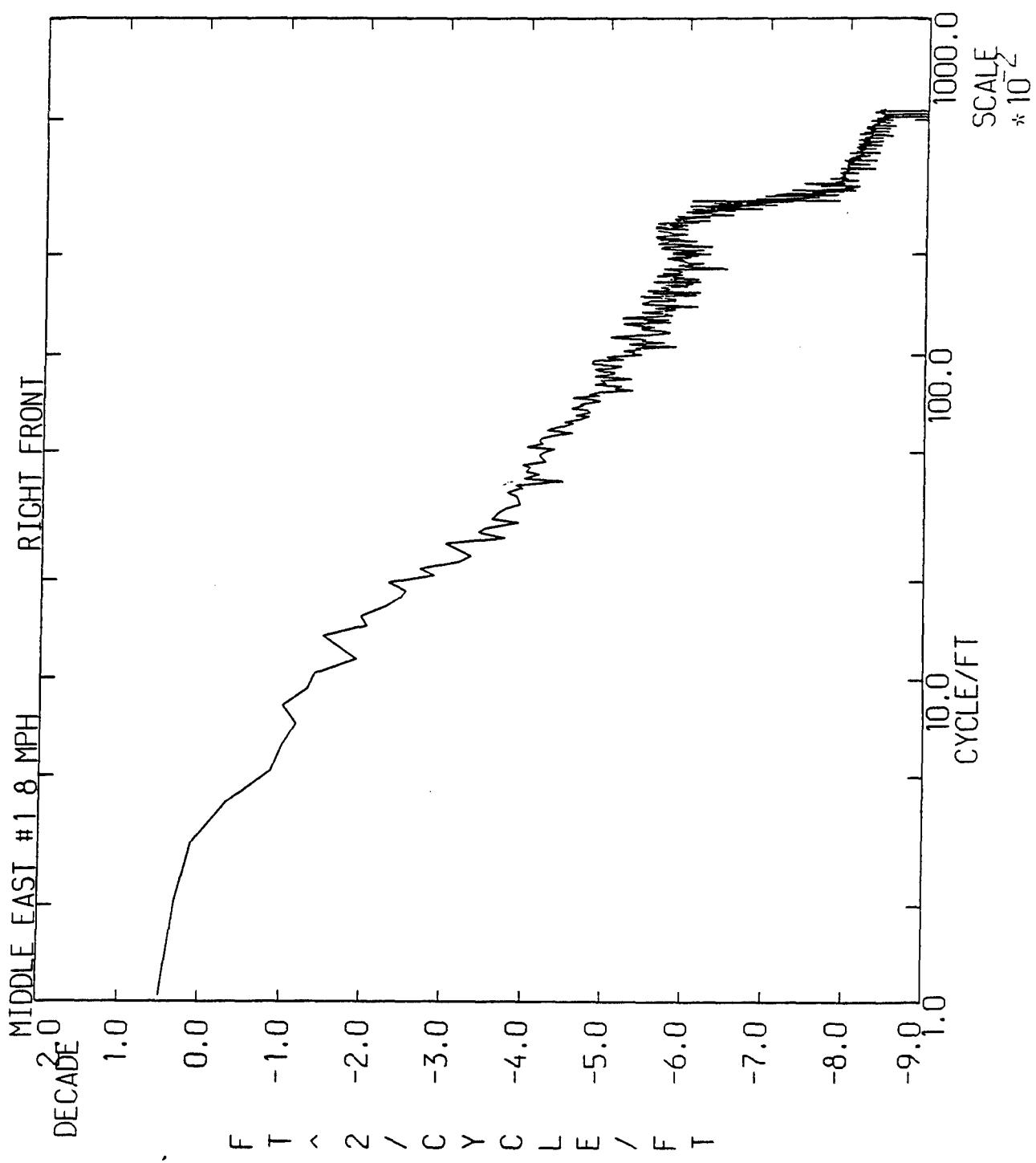


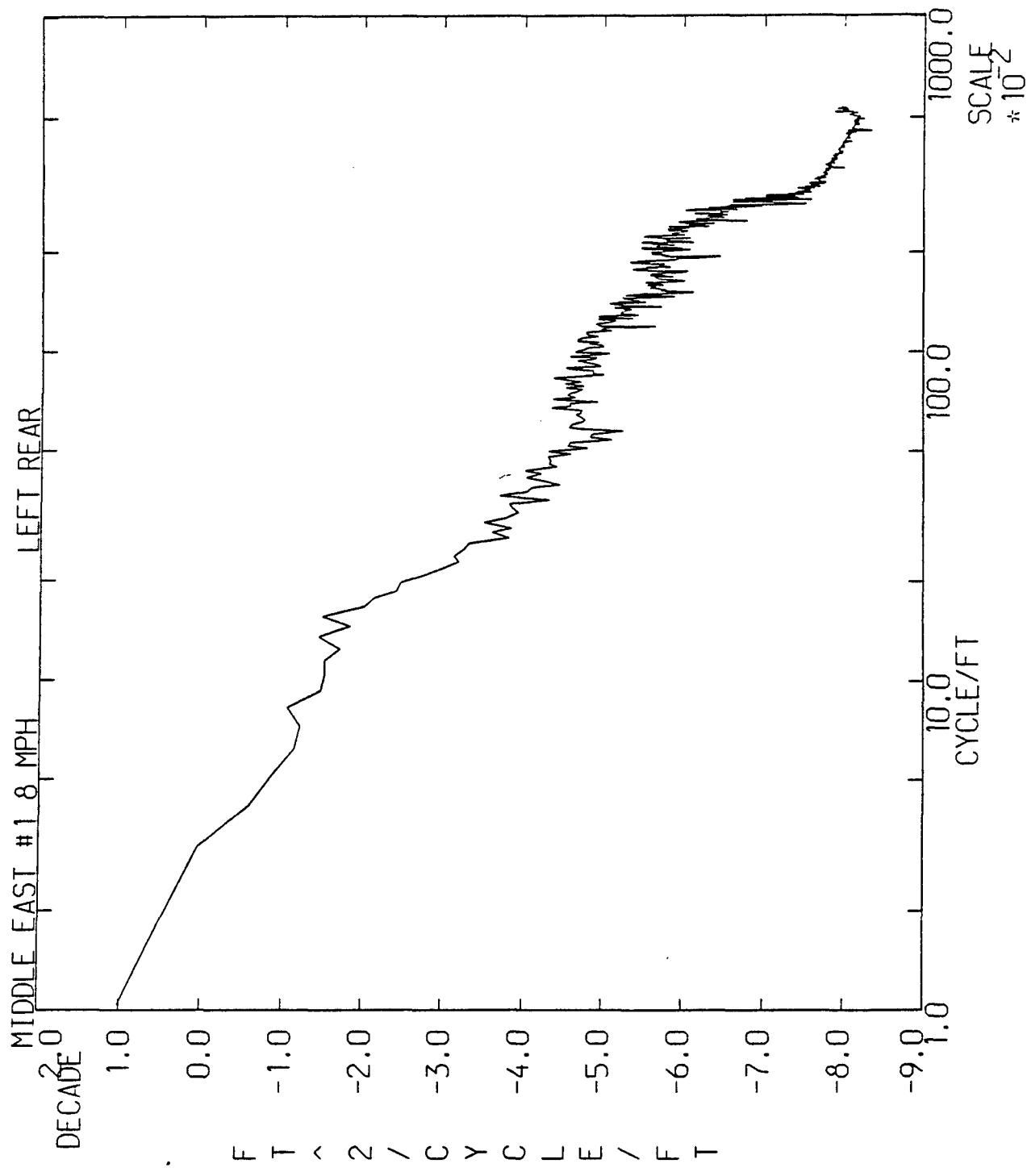


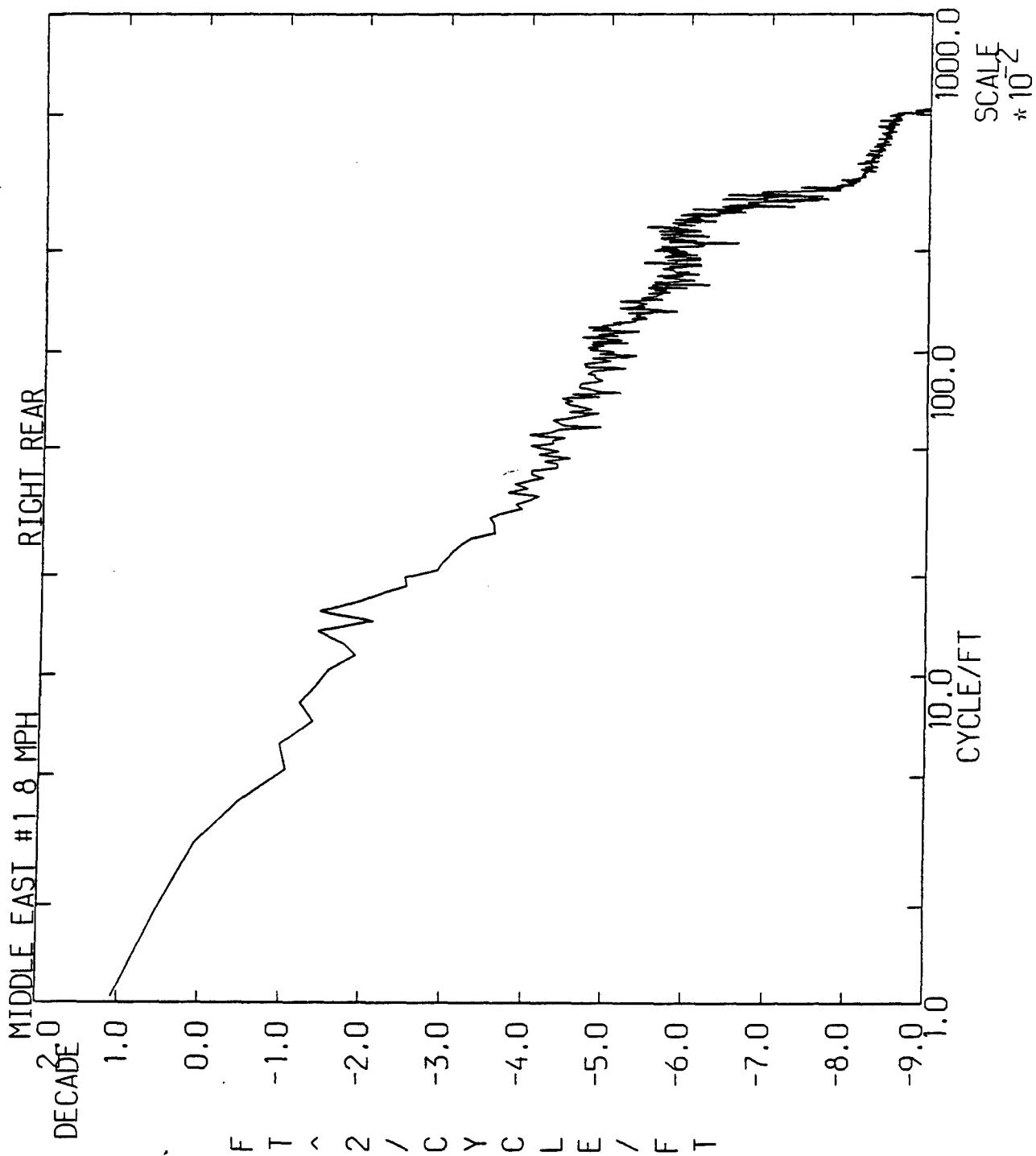


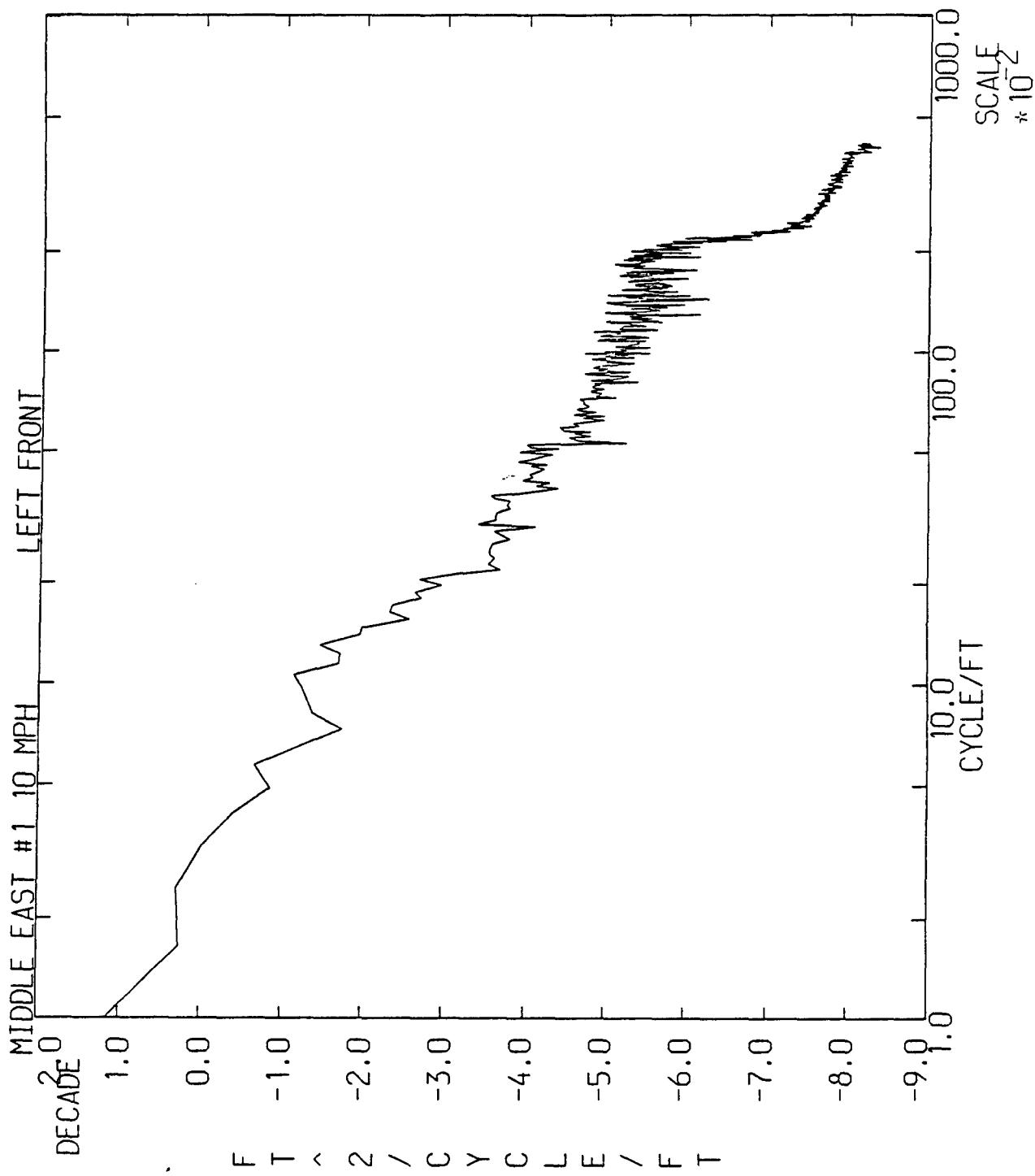


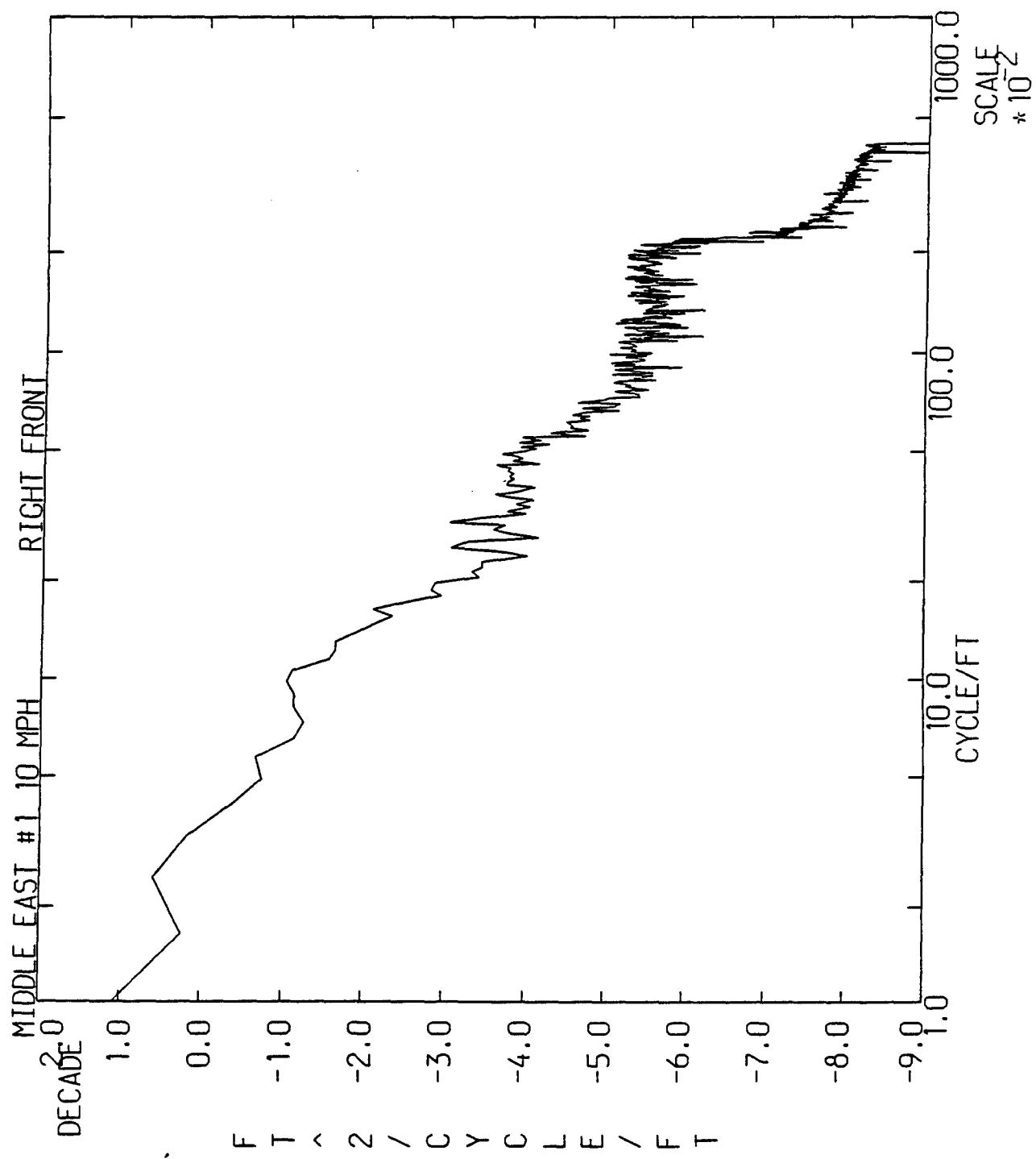


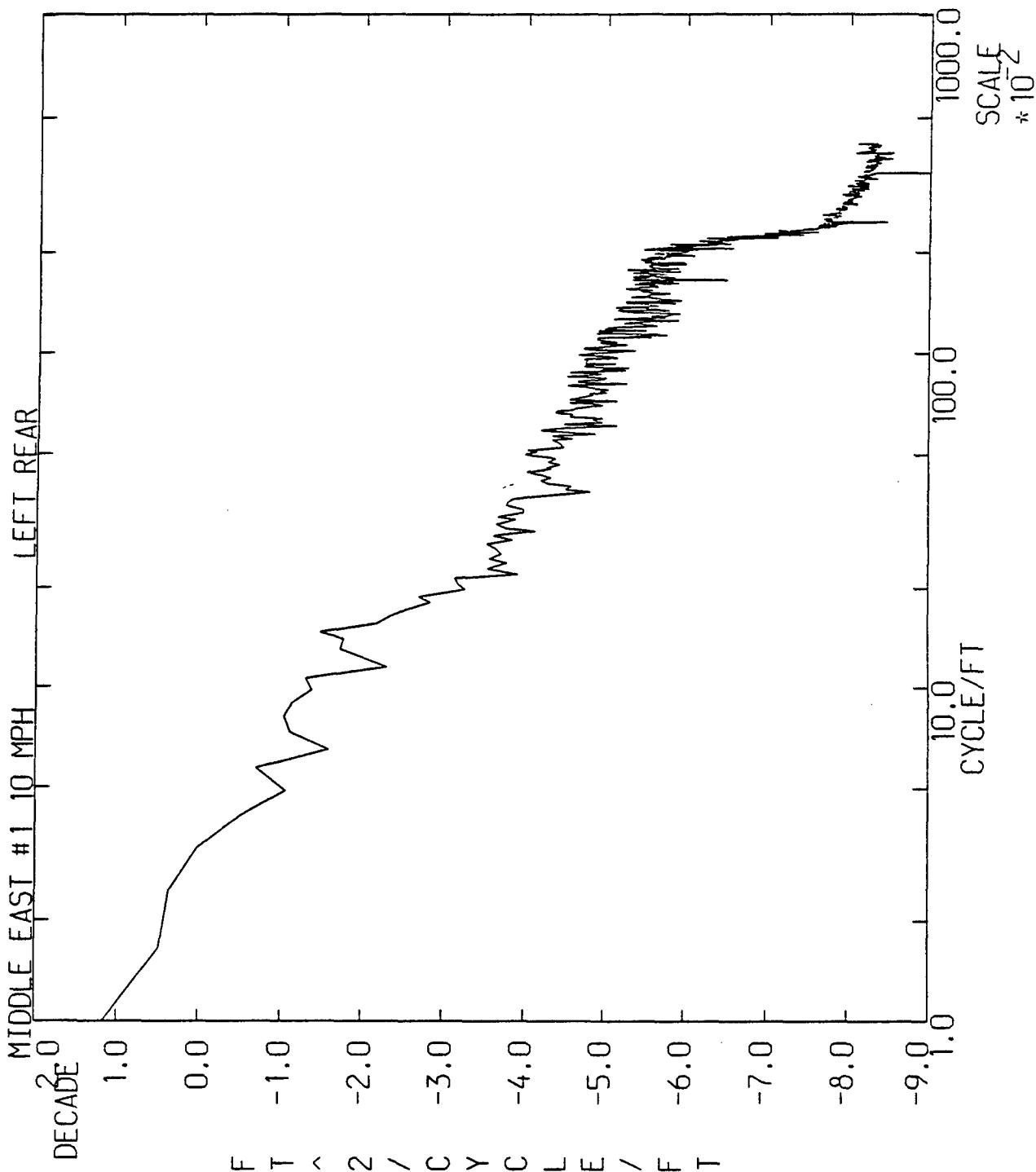


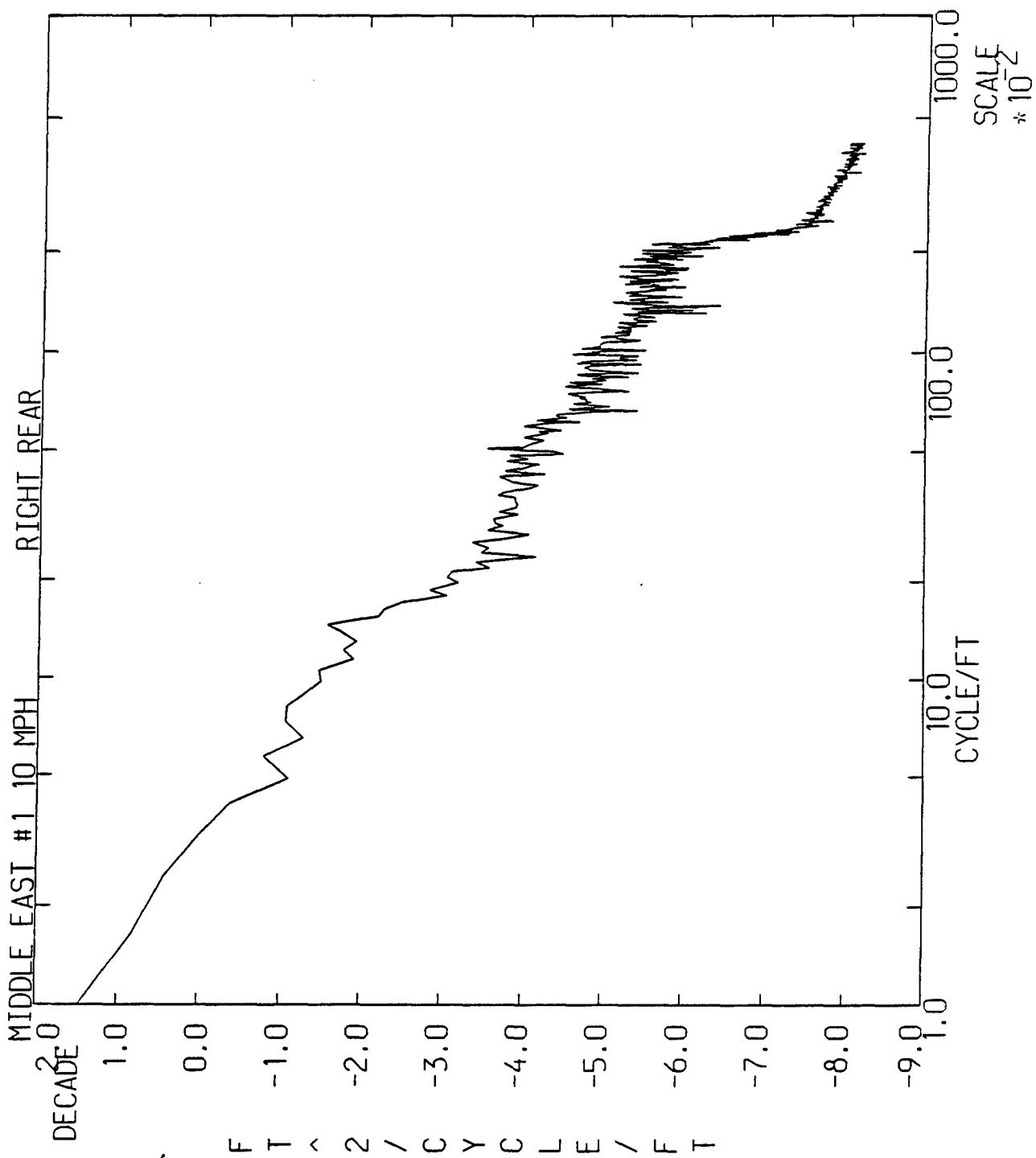












MIDDLE EAST #2

WAVE-NUMBER SPECTRA

2, 4, 6, 8 and 10 MPH

Four (4) curves per speed, one for each DFMV tire, as follows

**LEFT FRONT
RIGHT FRONT
LEFT REAR
RIGHT REAR**

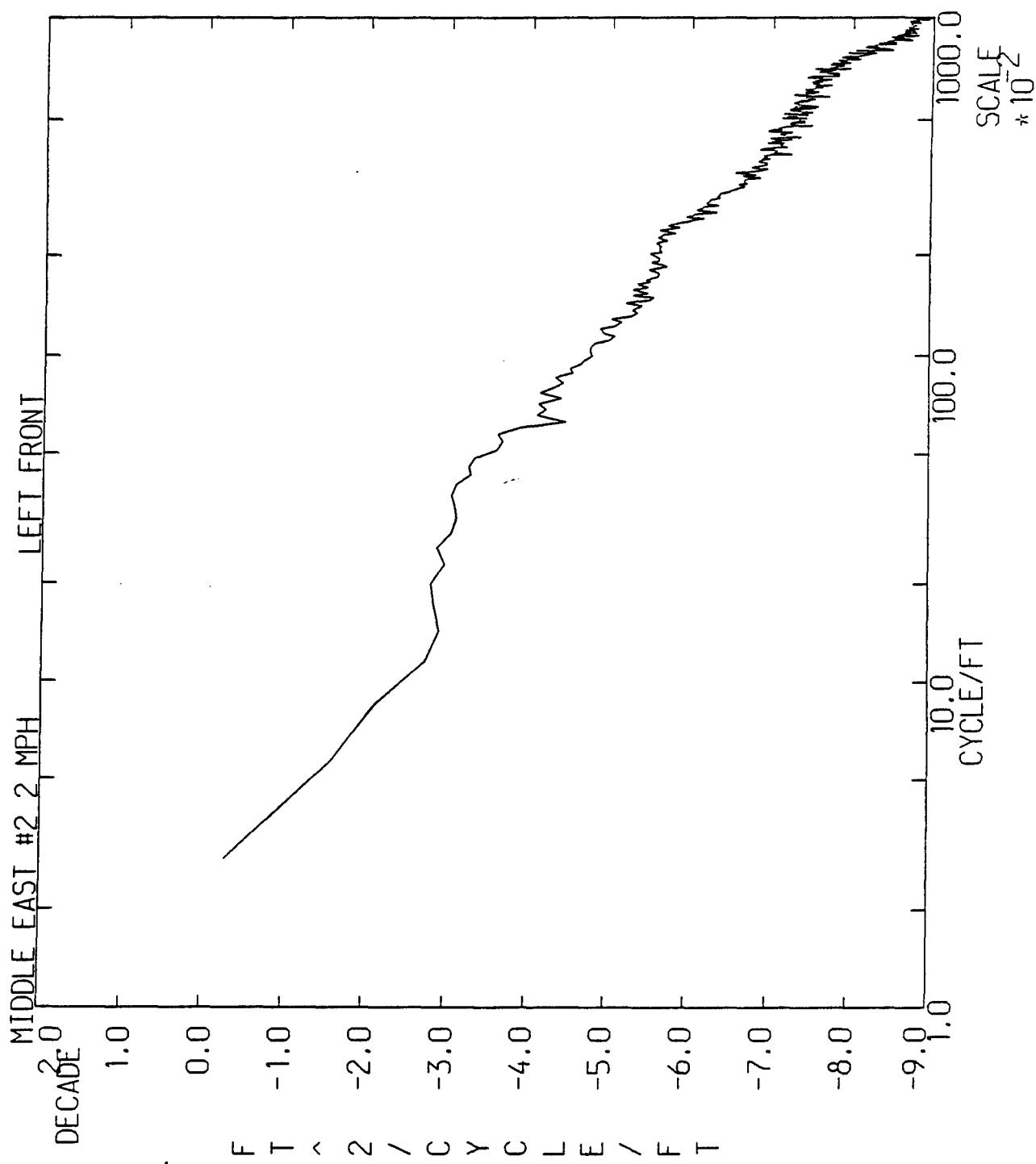
Volume II contains the data for the different DFMV speeds over each YPG course. The data was previously submitted to TACOM in an interim data report, however, the data was not reprocessed with the signal processing considerations discussed in the Volume I report (e.g., in this data, much of the spectral resolution was below the footprint). The wave-number cut-off at the low end of the spectra was limited by the frequency range of the accelerometer, as discussed in the report and shown in the table below. The wave-number cut-off at the high end of the spectrum was limited by the footprint length of the DFMV tire, which was $\approx 1.2 \text{ ft}^{-1}$. These cut-offs were verified through the DFMV front-to-rear coherence plots. Therefore, when comparing plots between different speeds, do not compare the data past these limits. As discussed in the report, the faster speed runs produced the best results at the lower wave numbers.

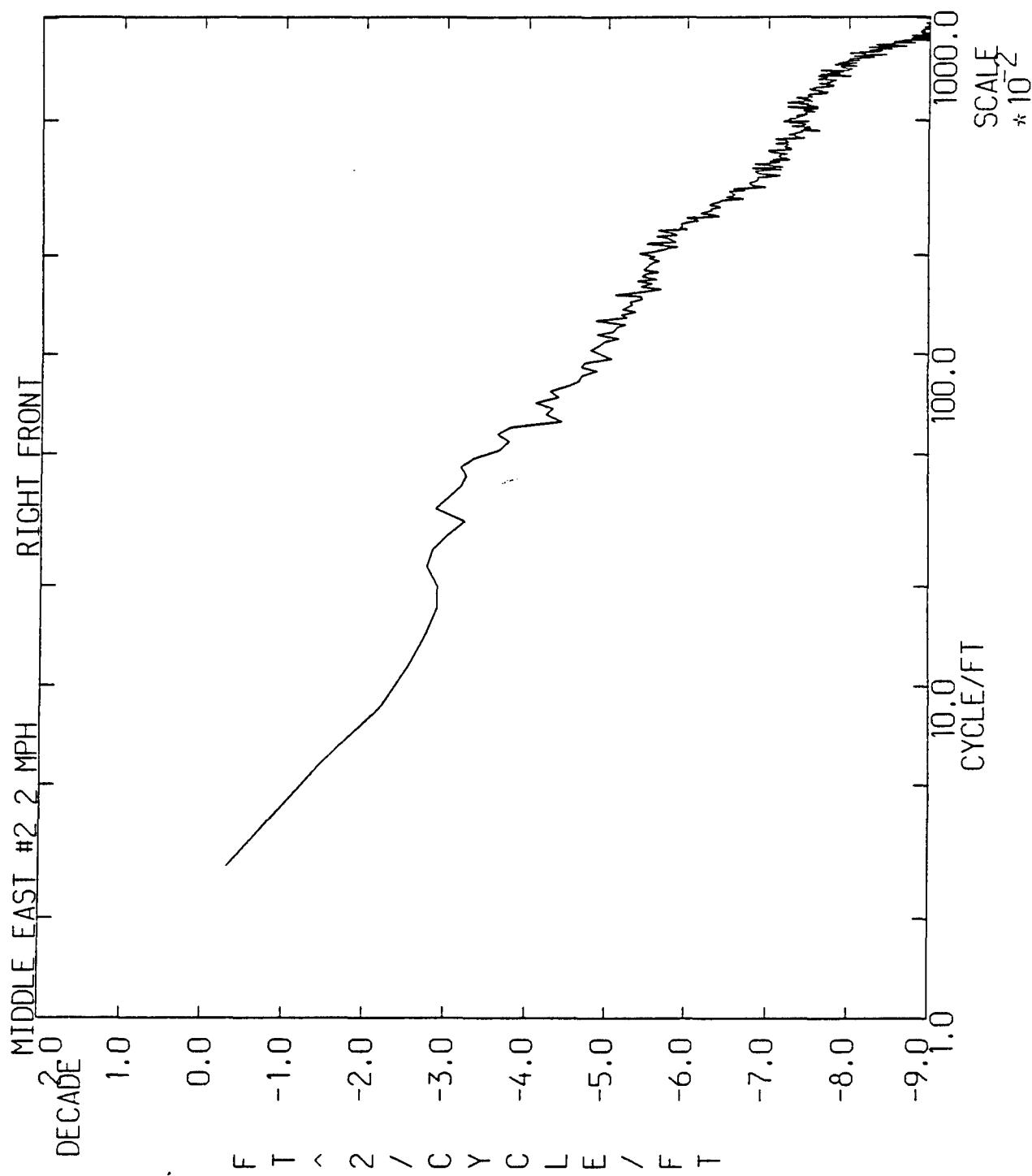
Table 1. DFMV Actual Versus Predicted Wavelength Limits

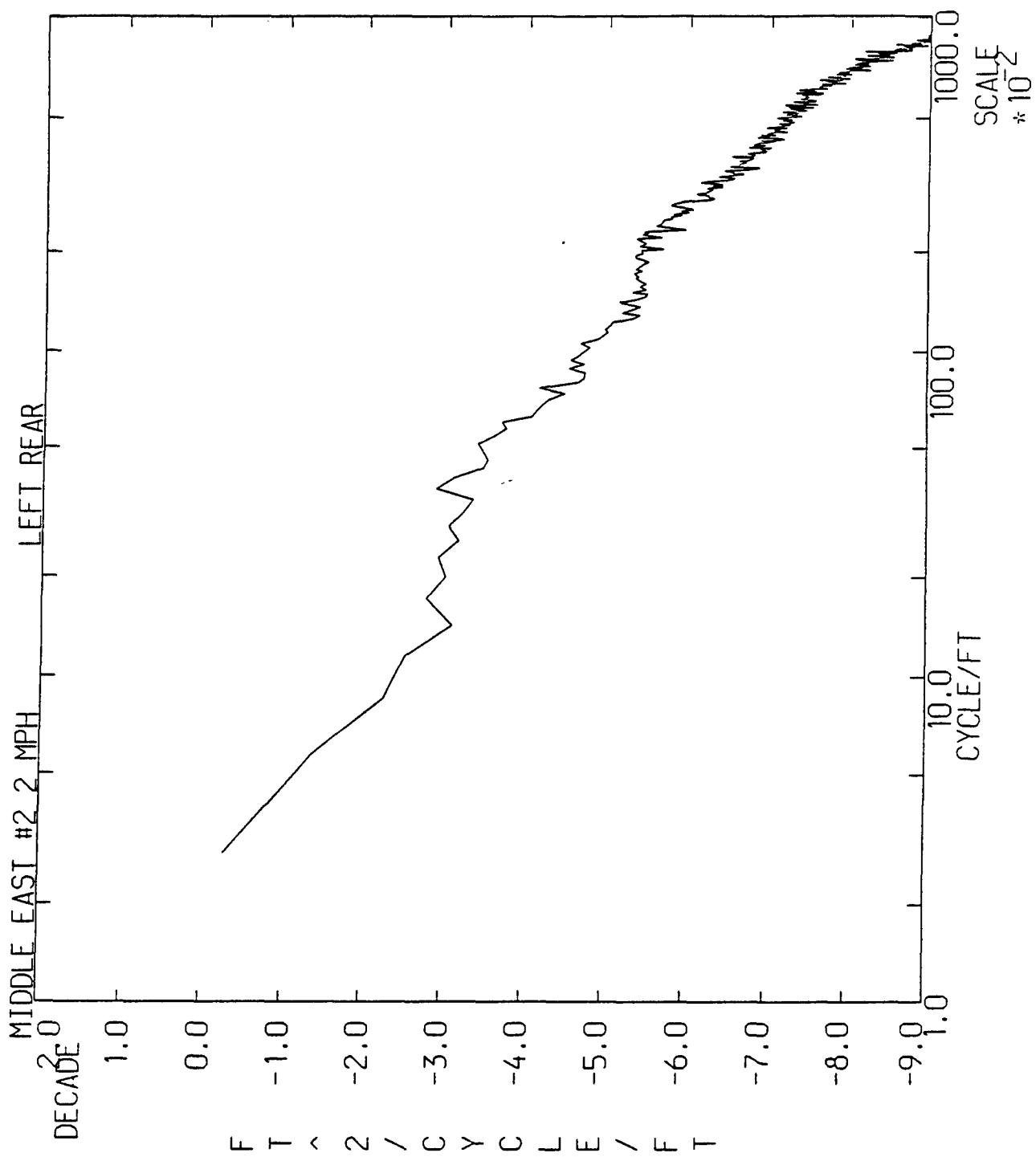
DFMV Speed MPH	Expected Wavelength Resolution*	Actual Wavelength Resolution**
2	60	15
4	120	30
6	180	45
8	240	60
10	300	75

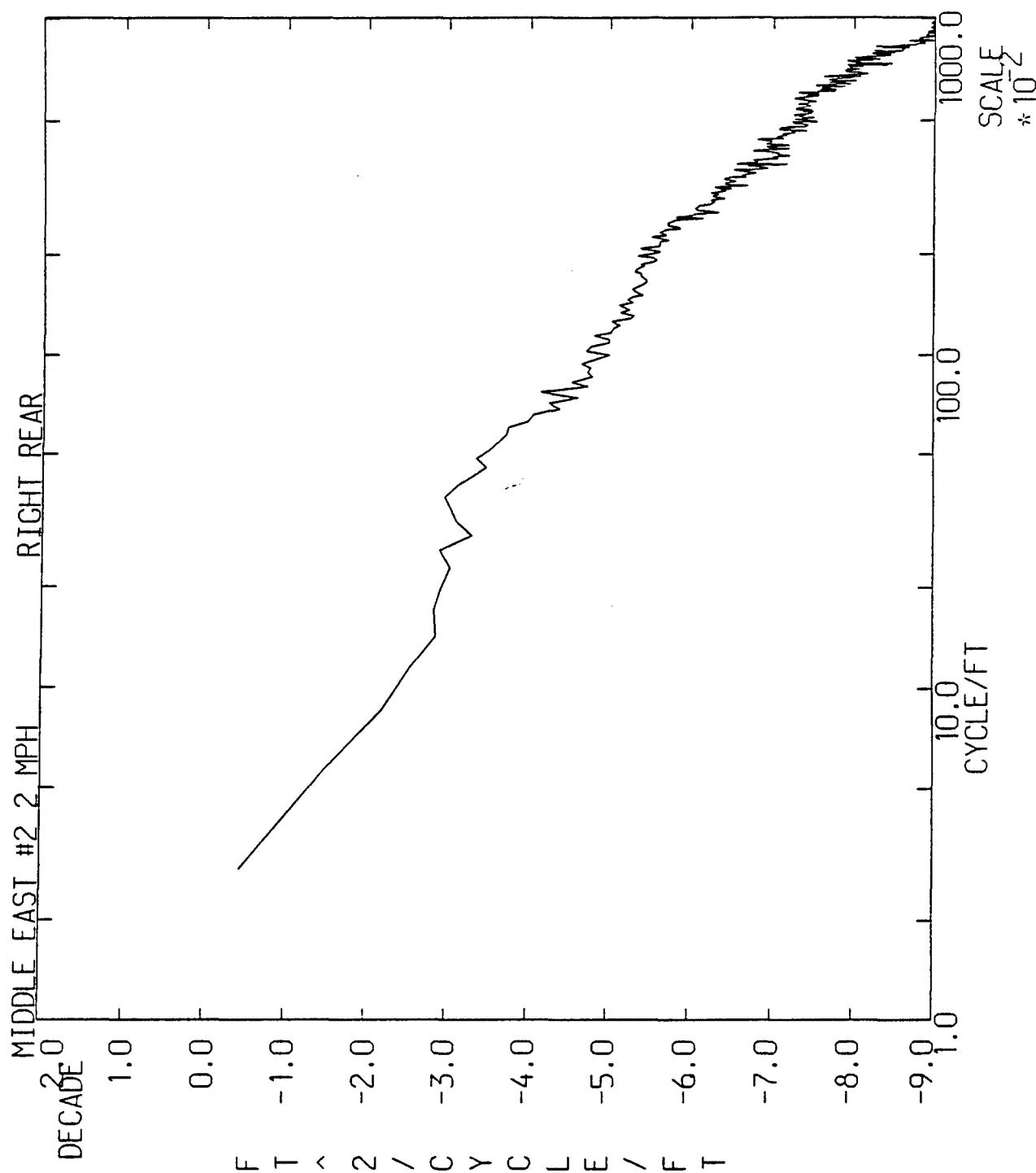
* Based on the advertised low-end frequency range for the accelerometer used

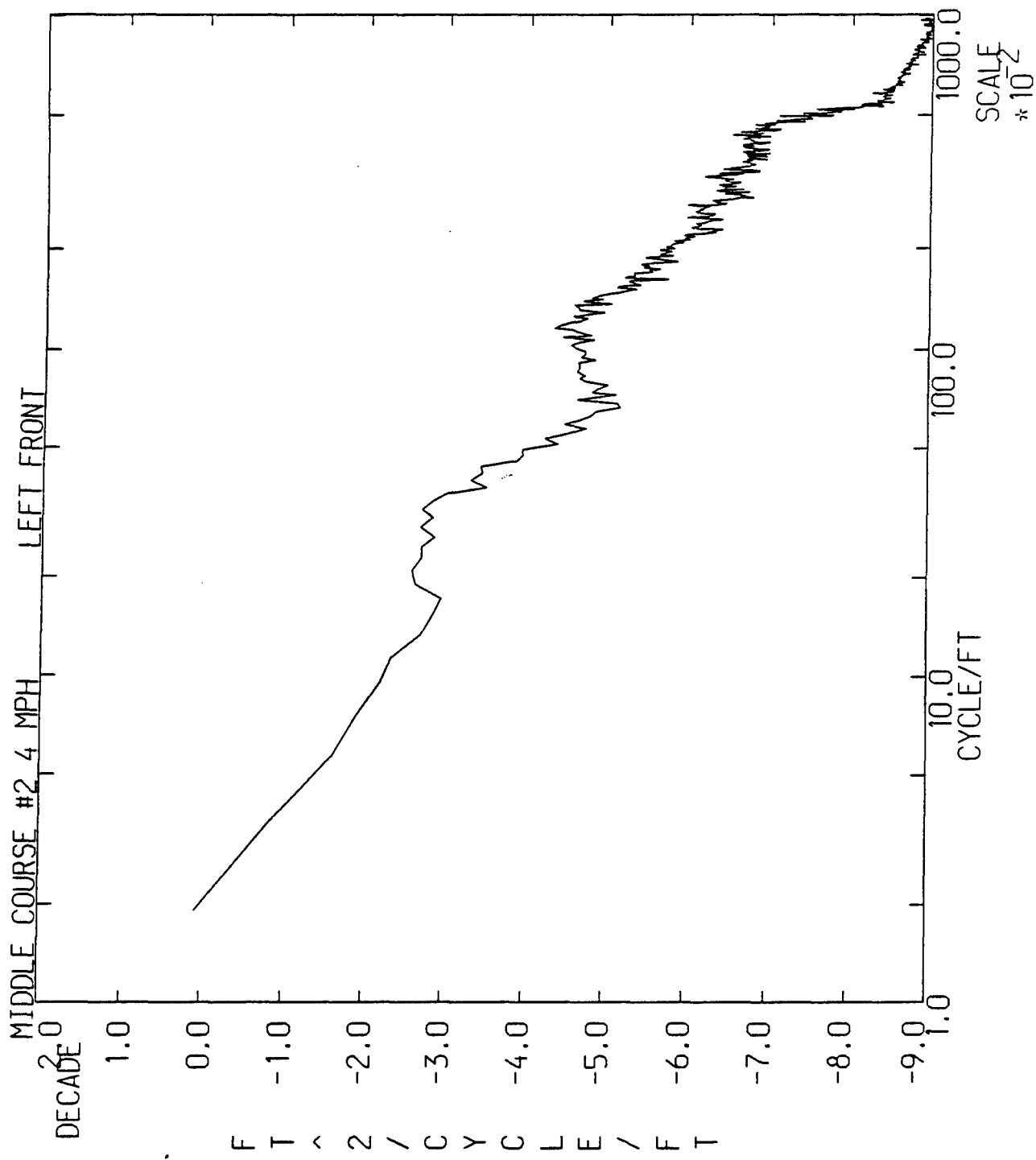
** Based on actual low-end frequency range for the accelerometer used

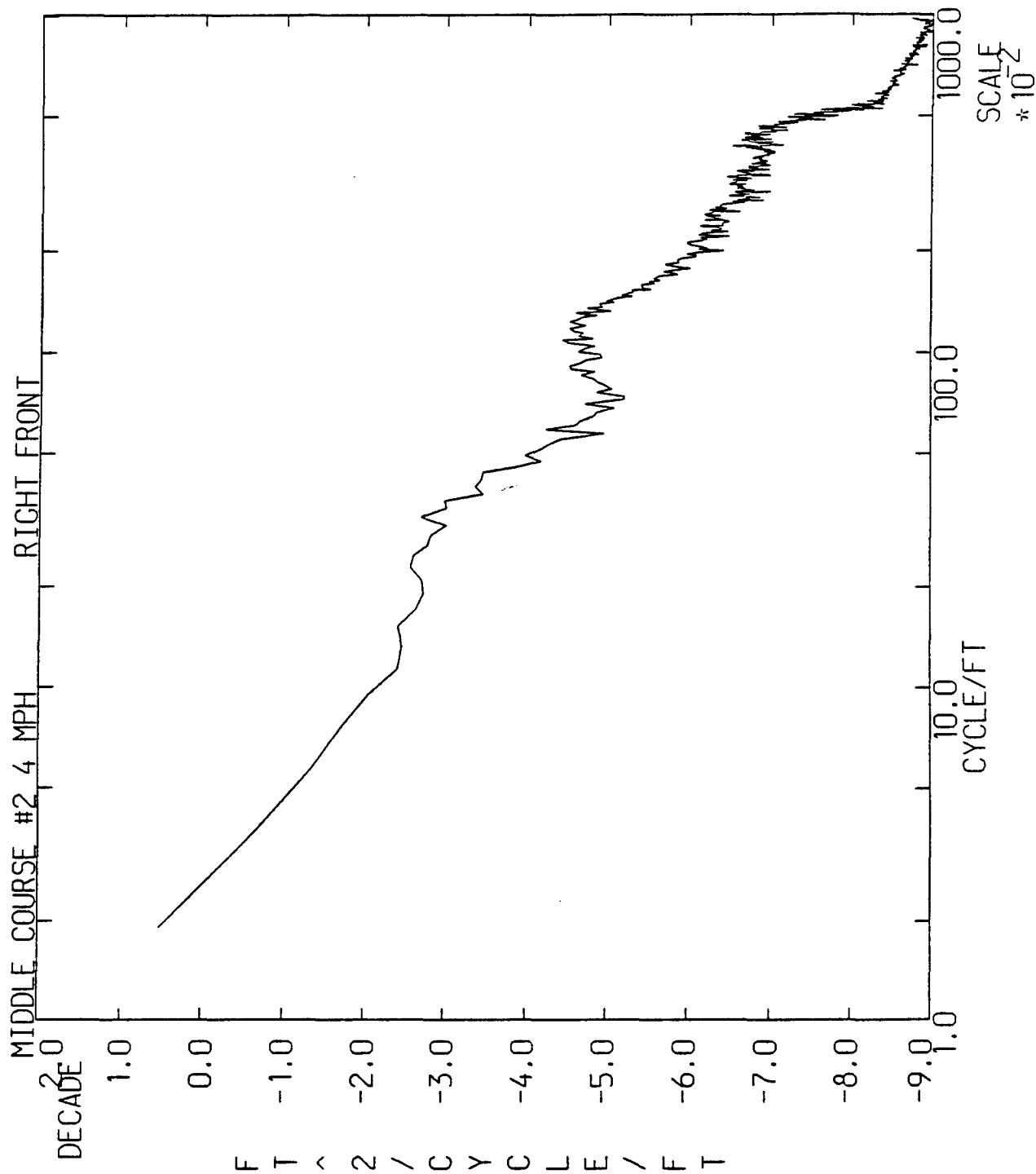


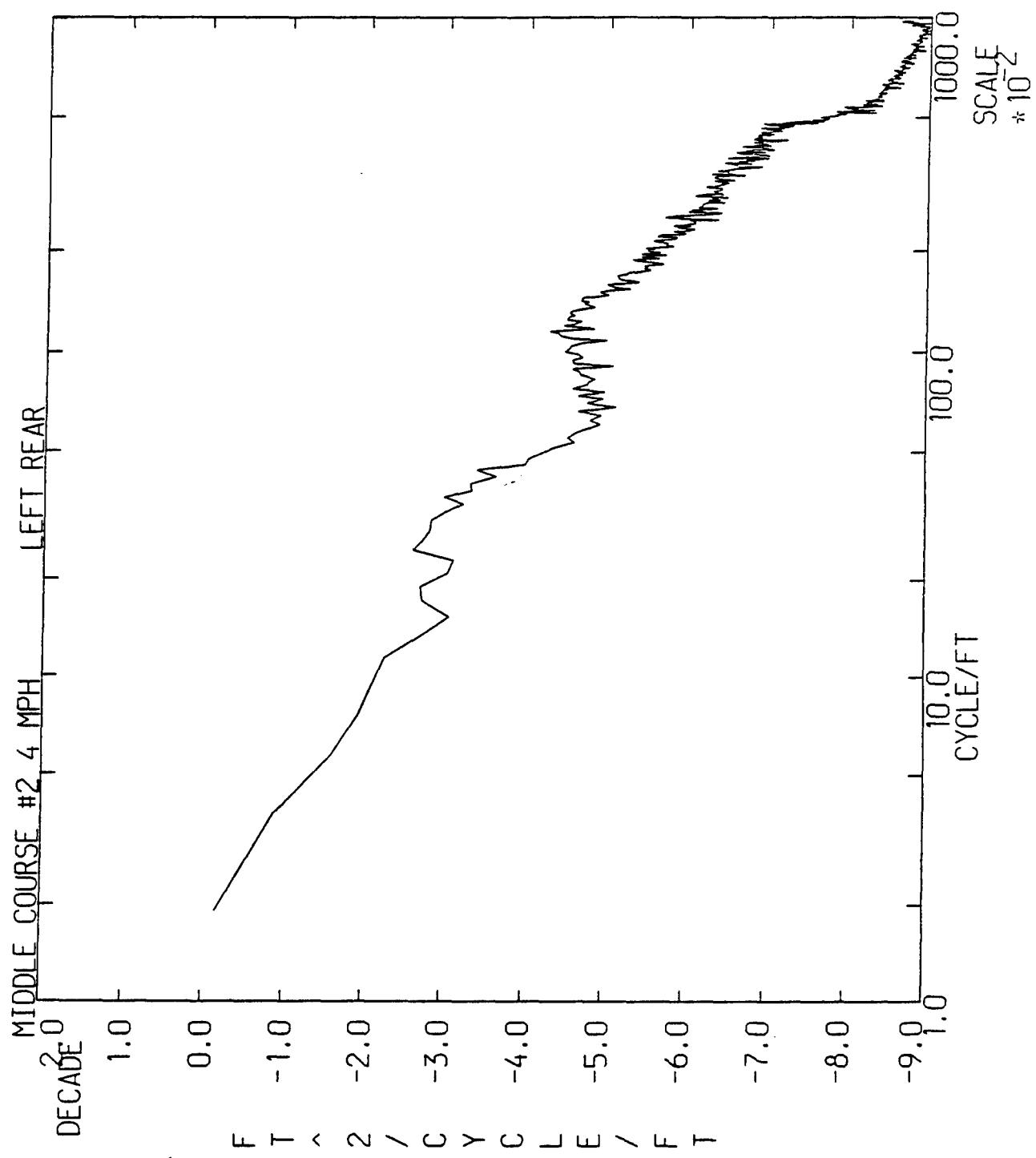


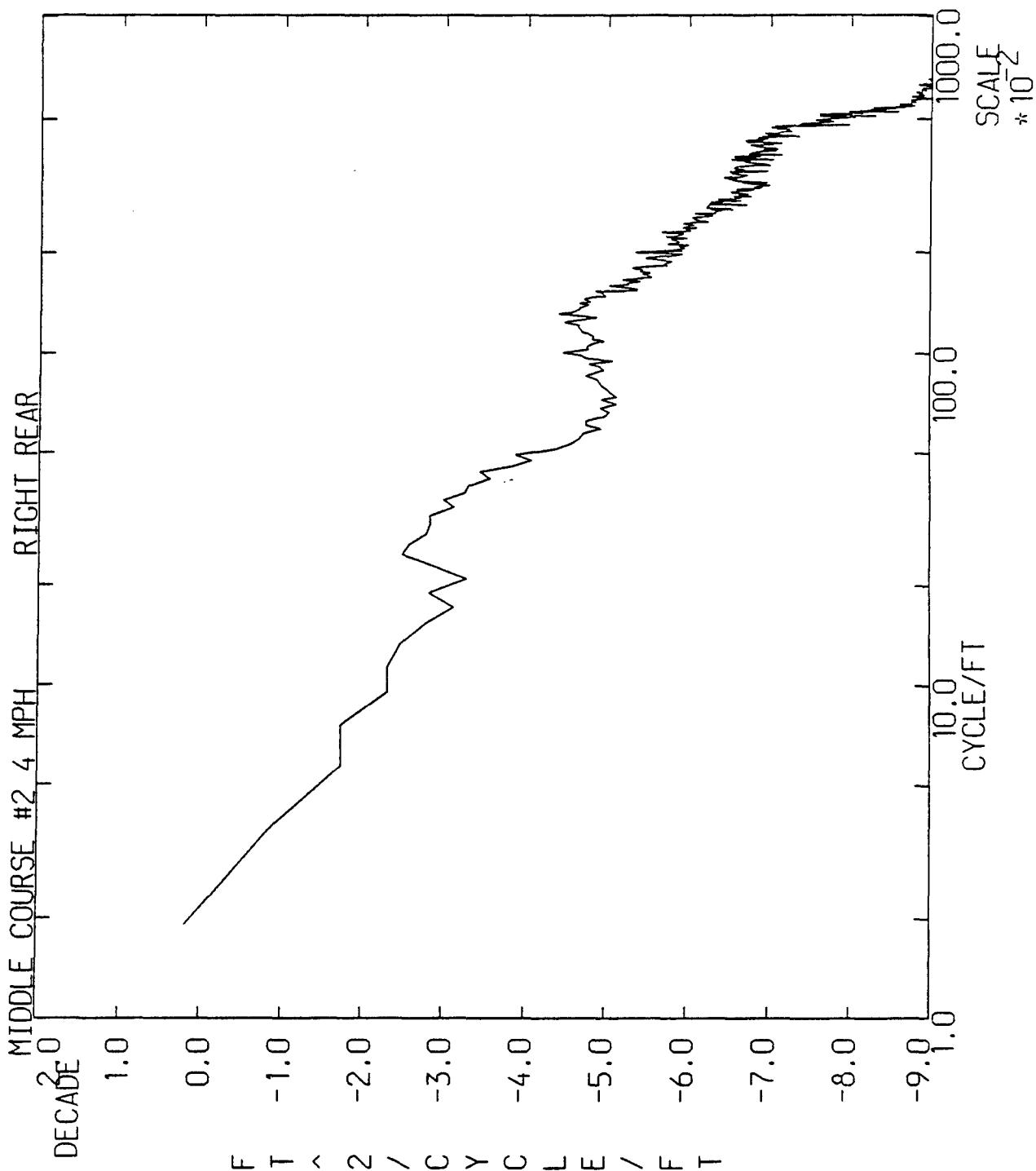


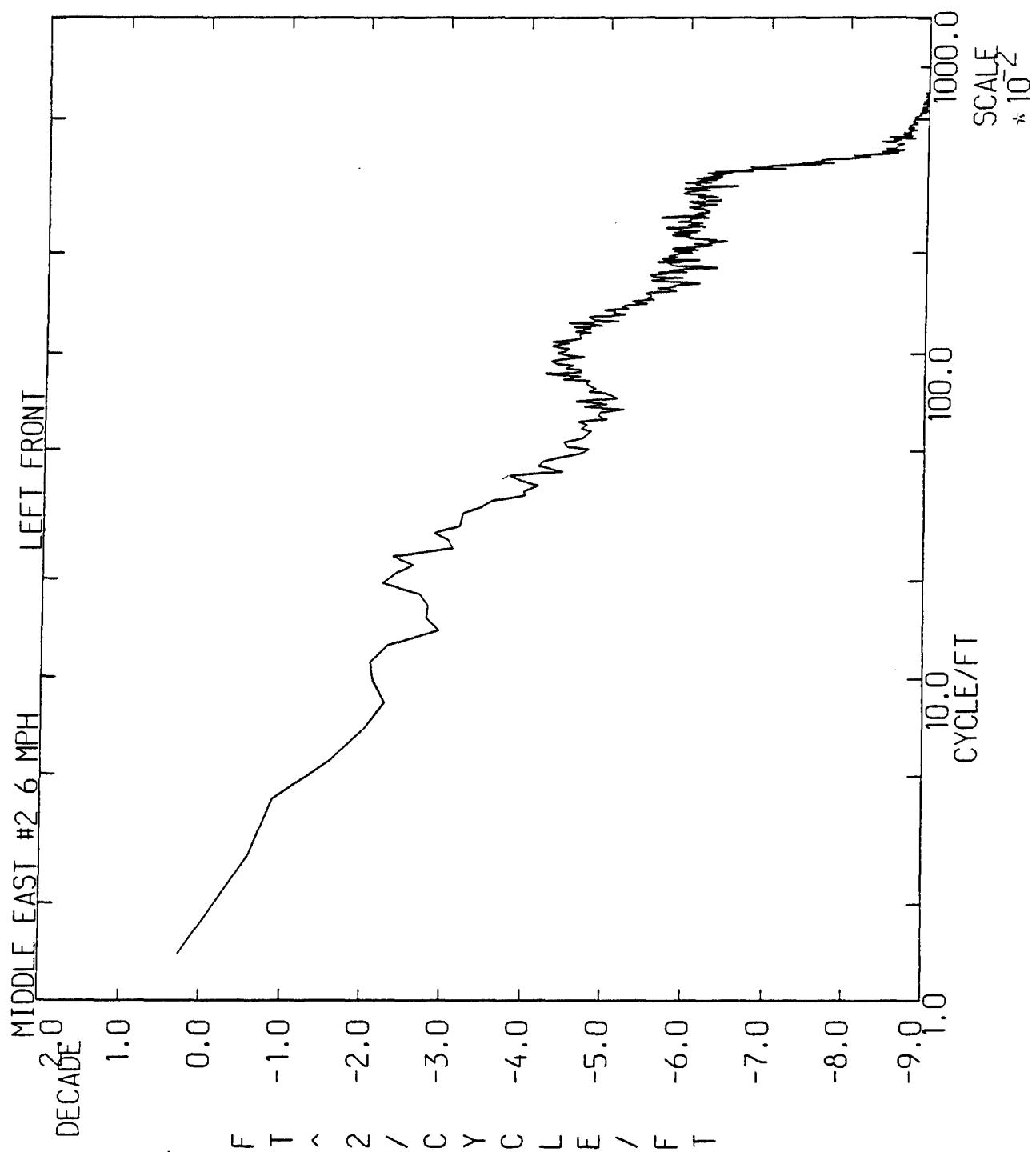


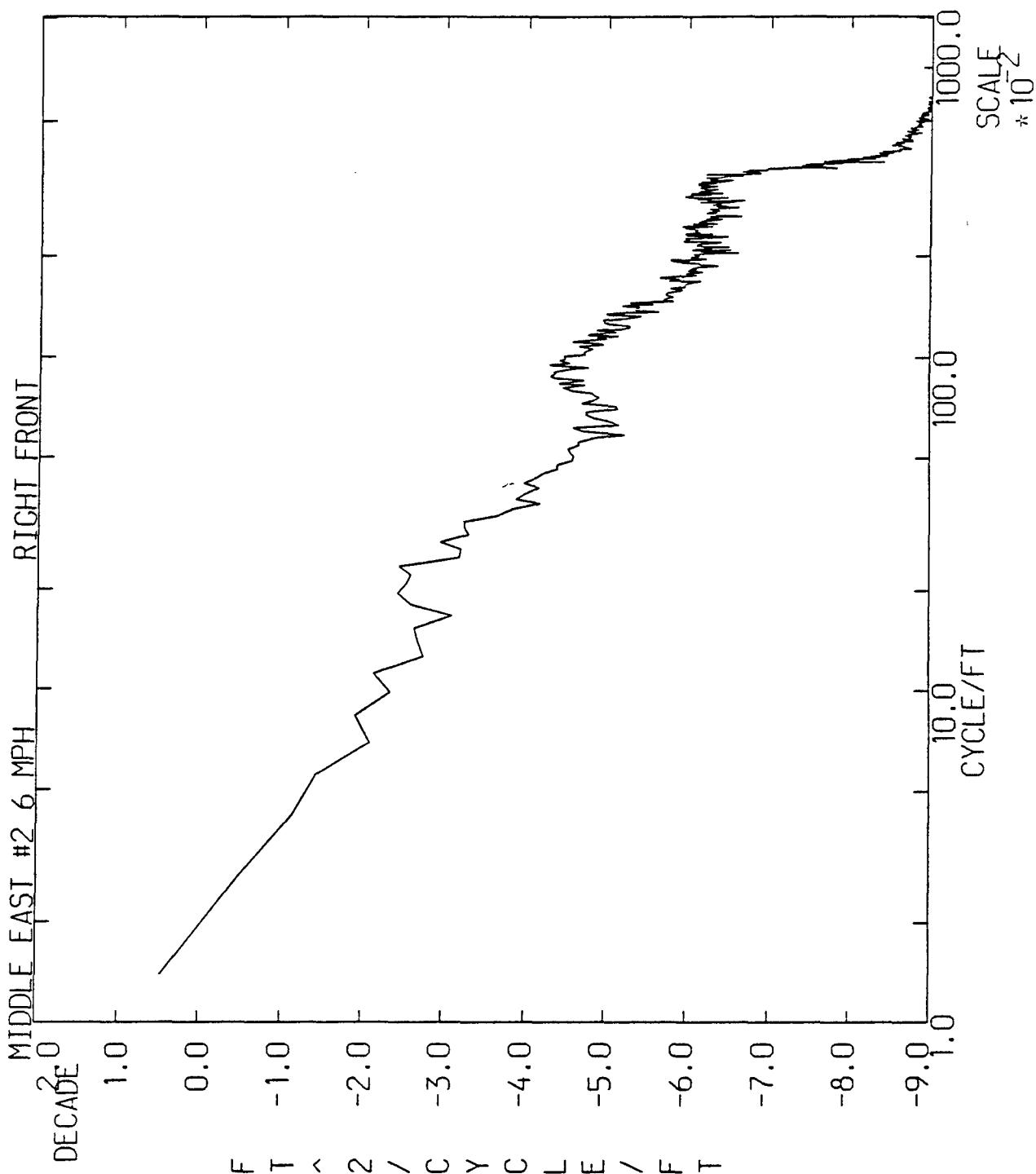


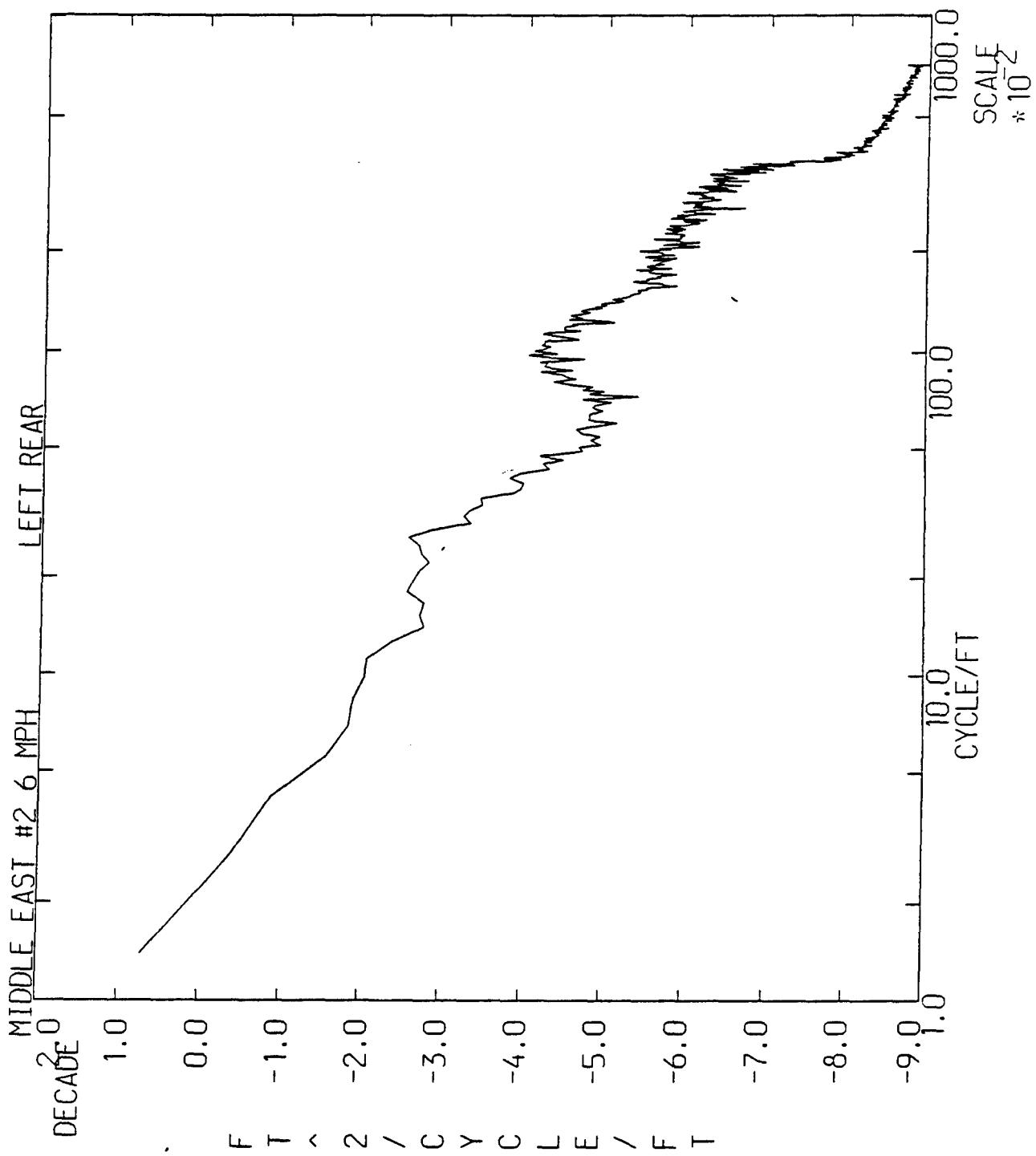


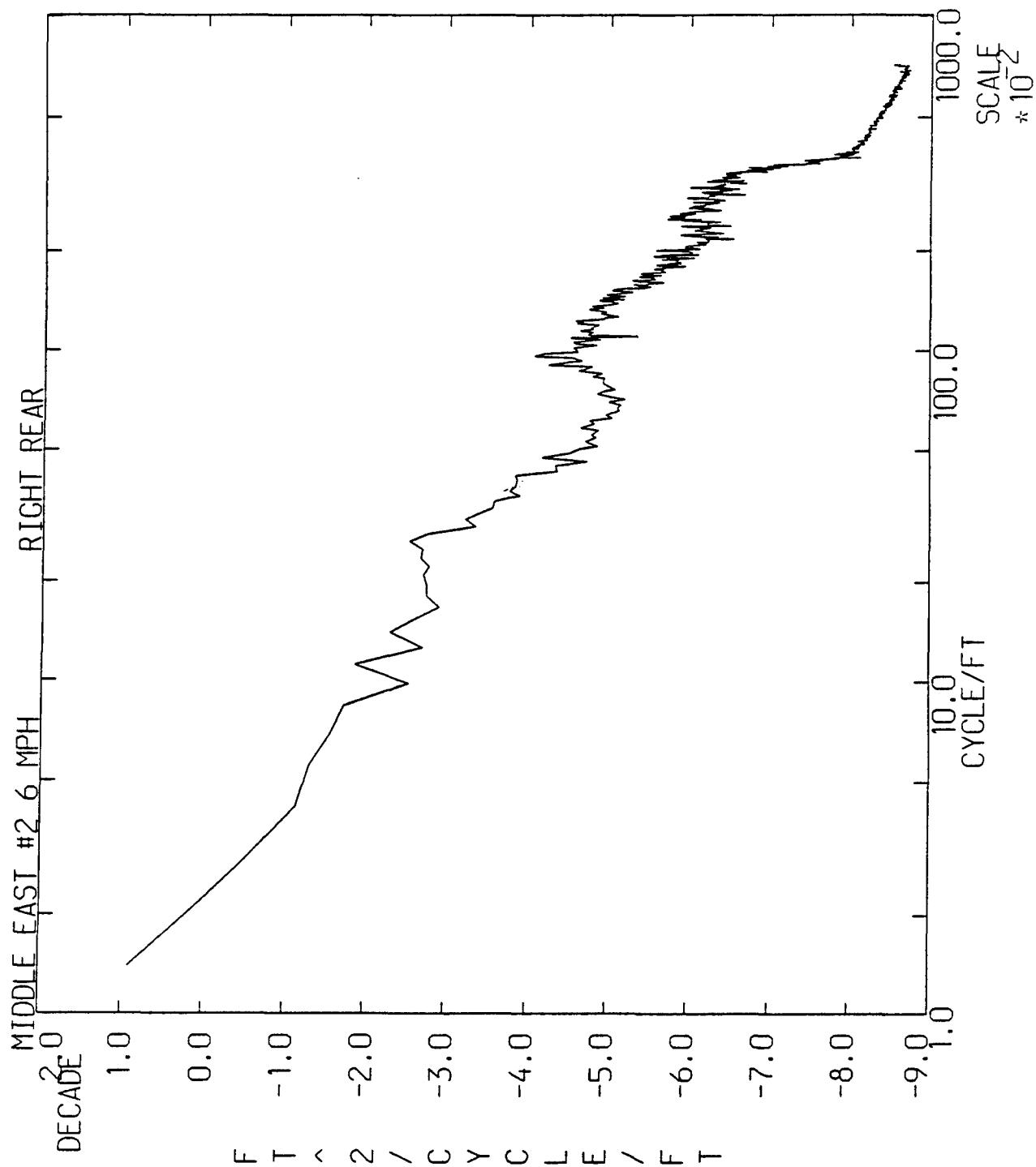


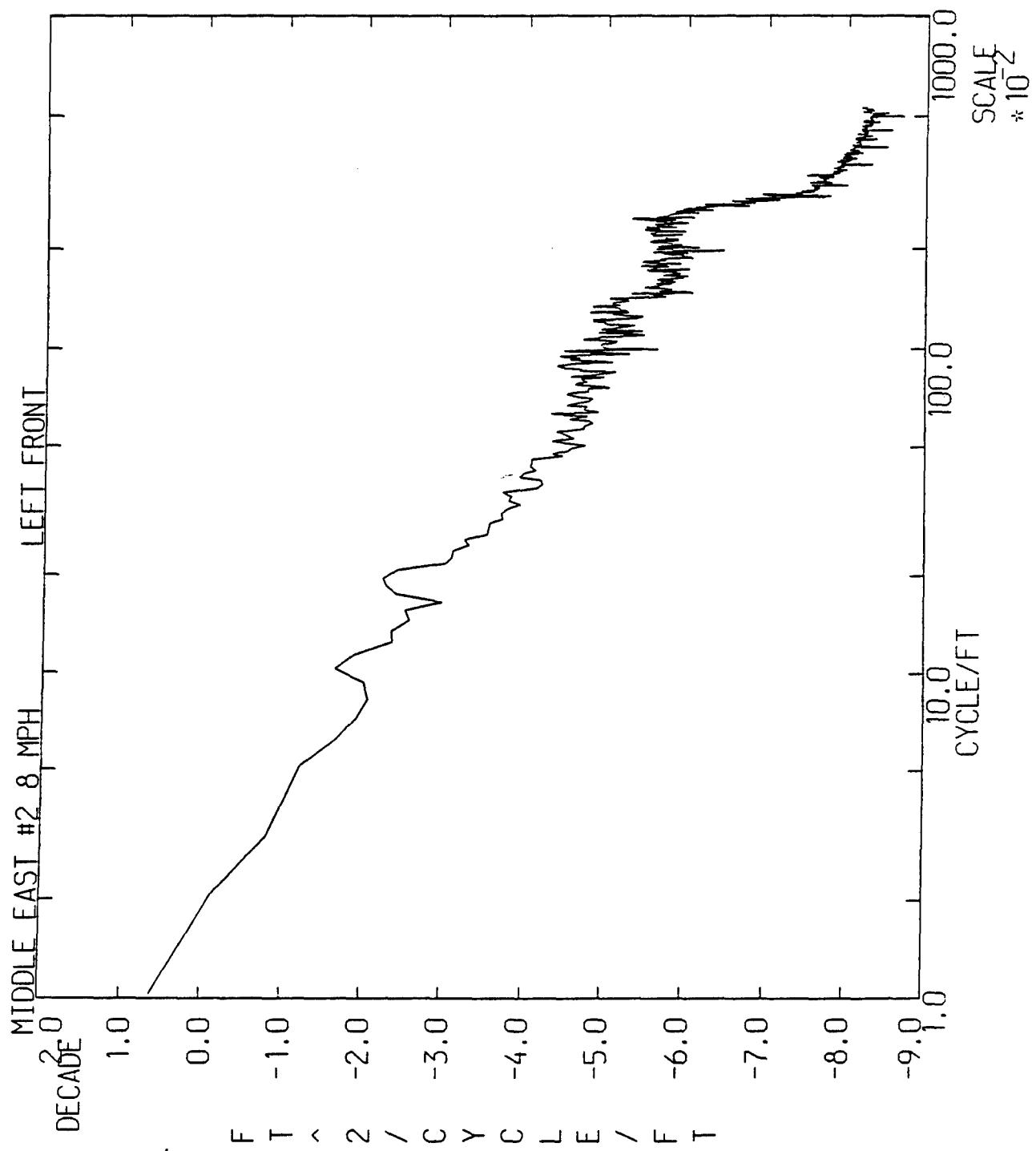


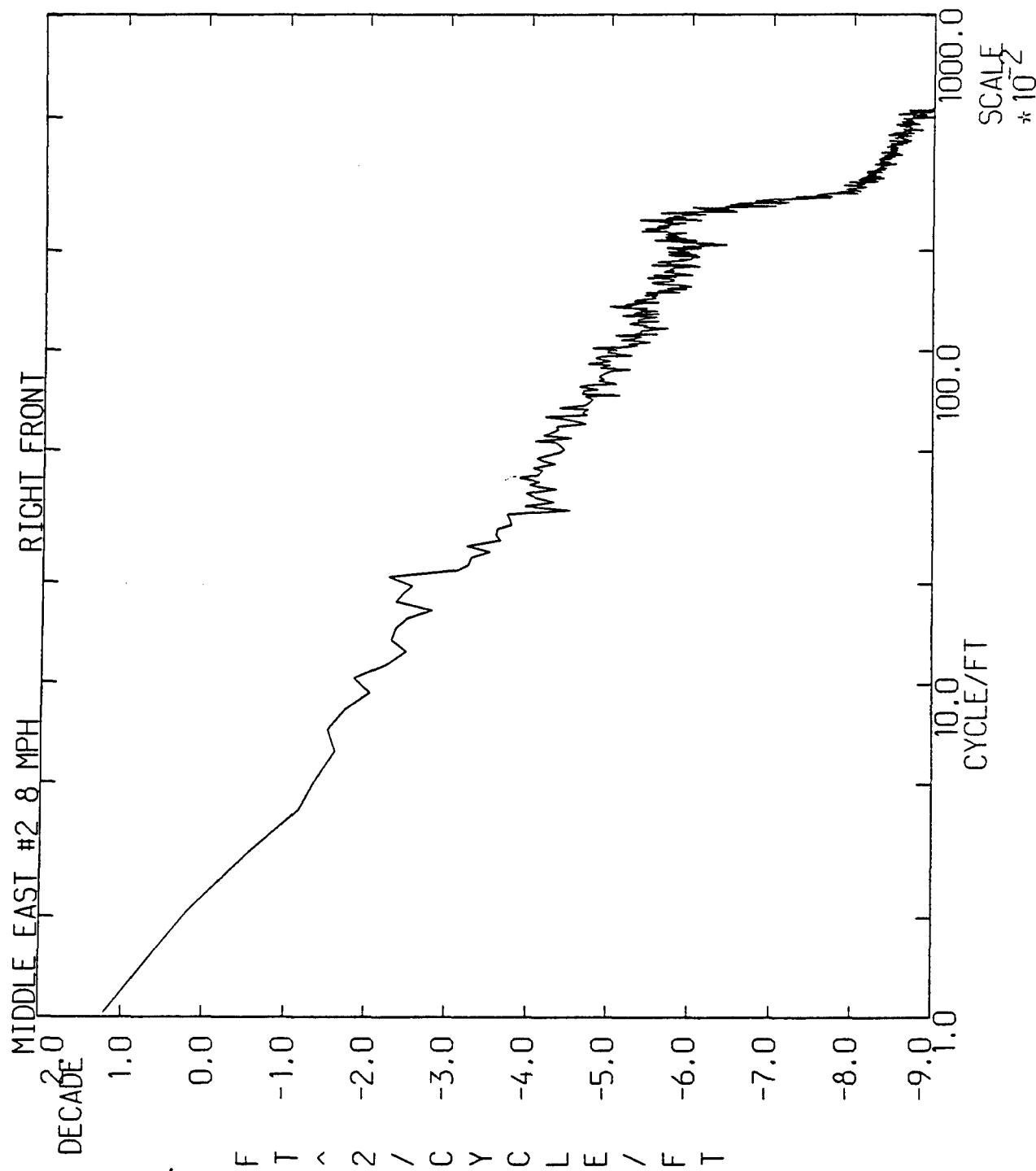


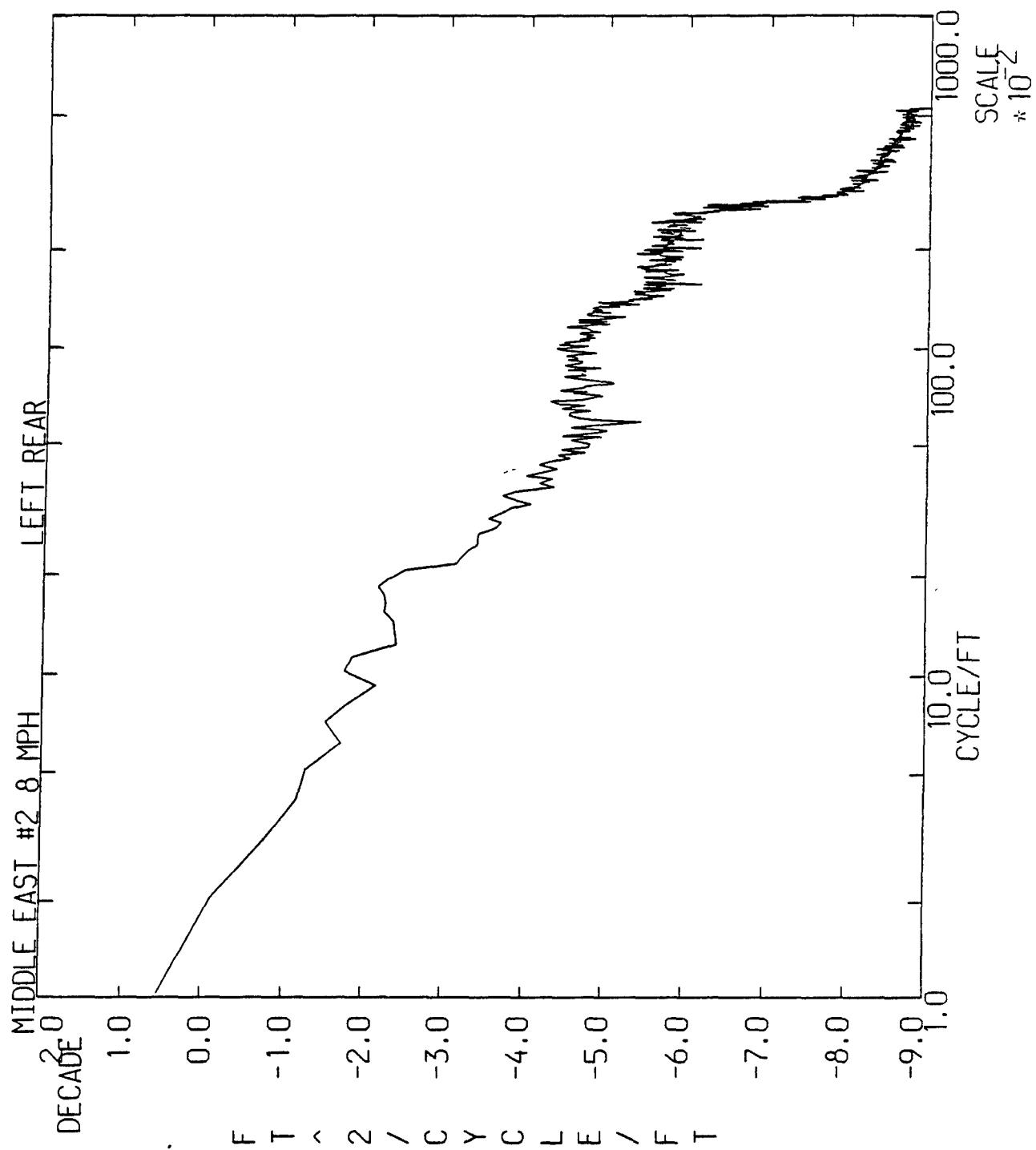


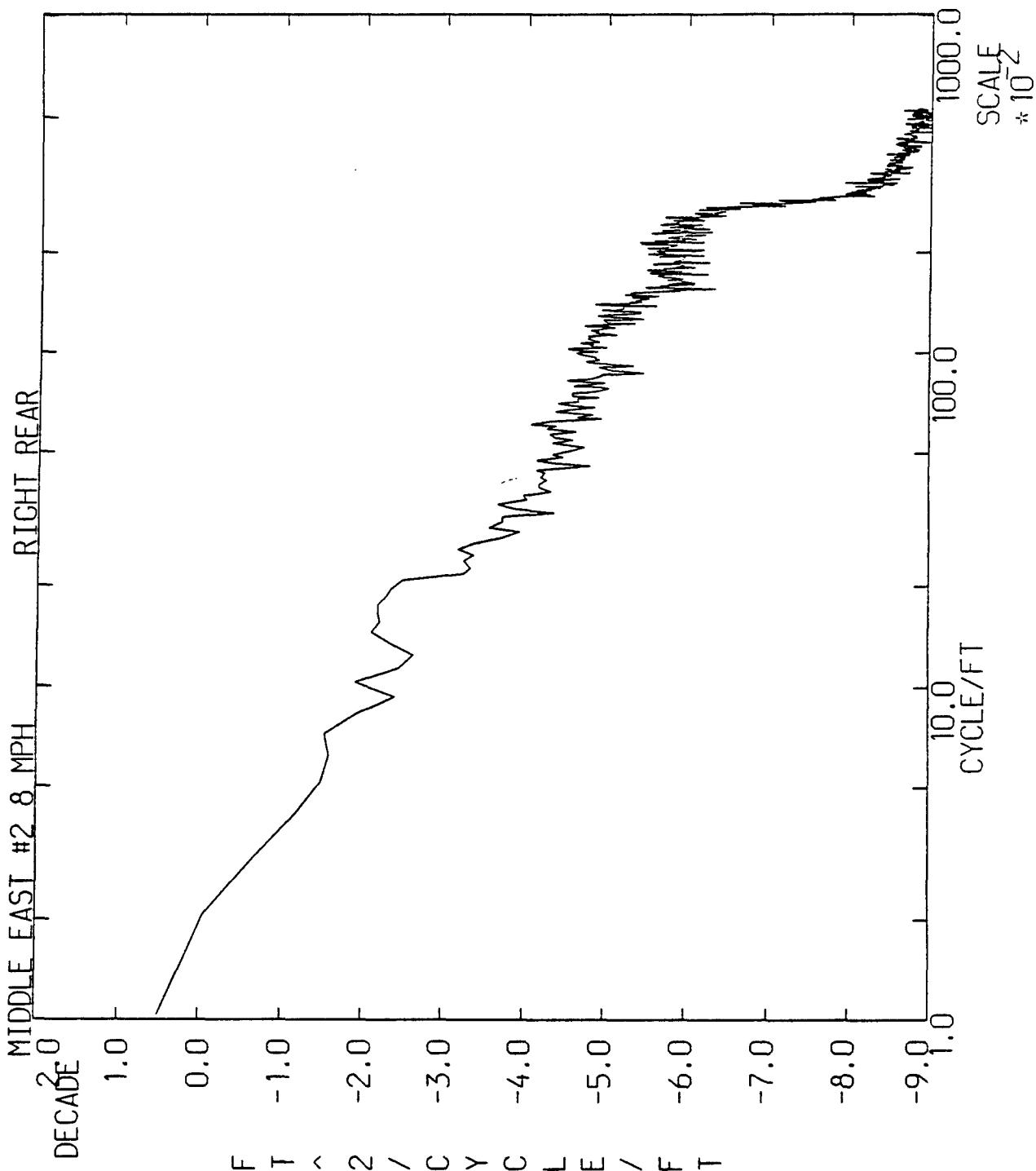


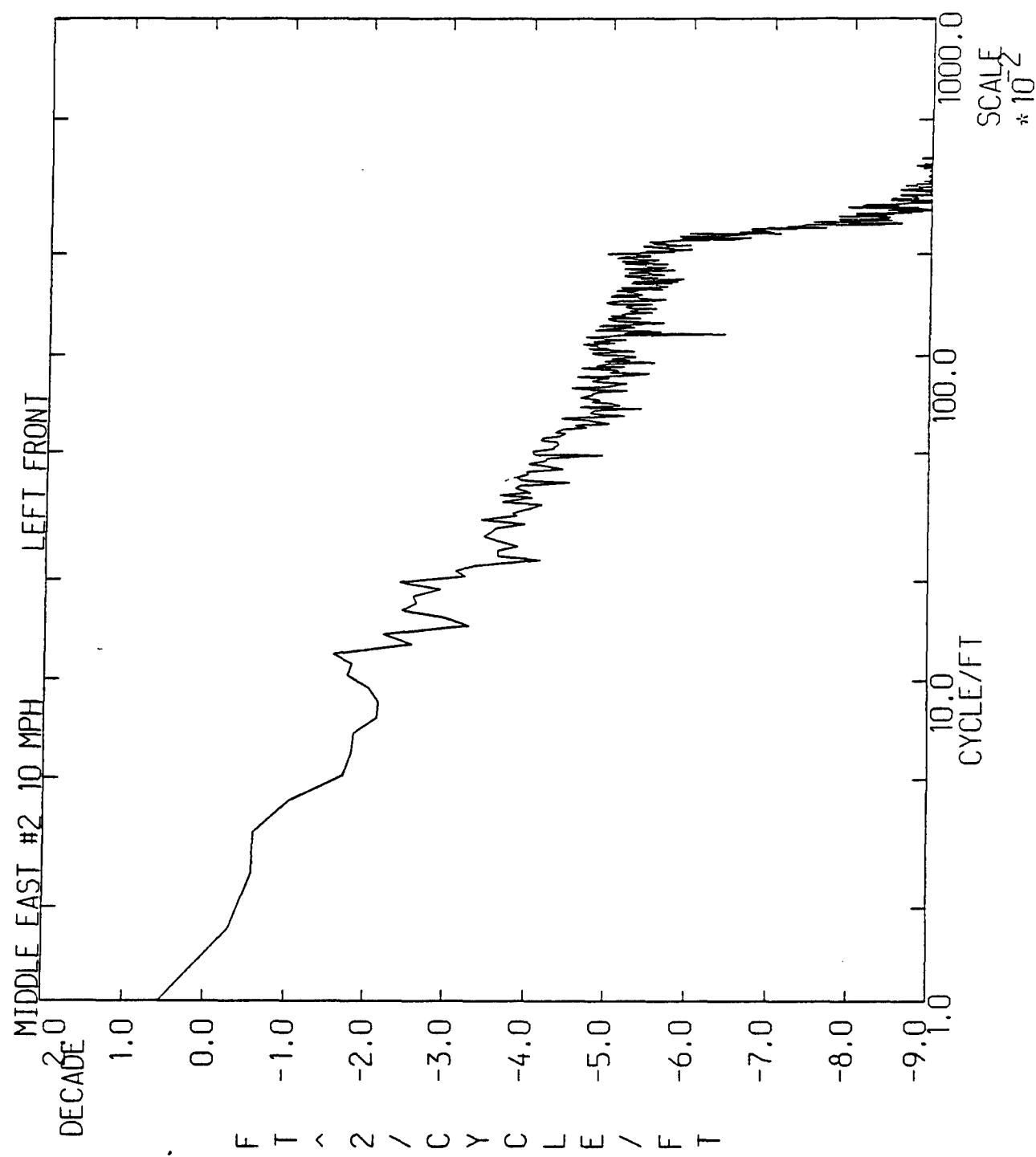


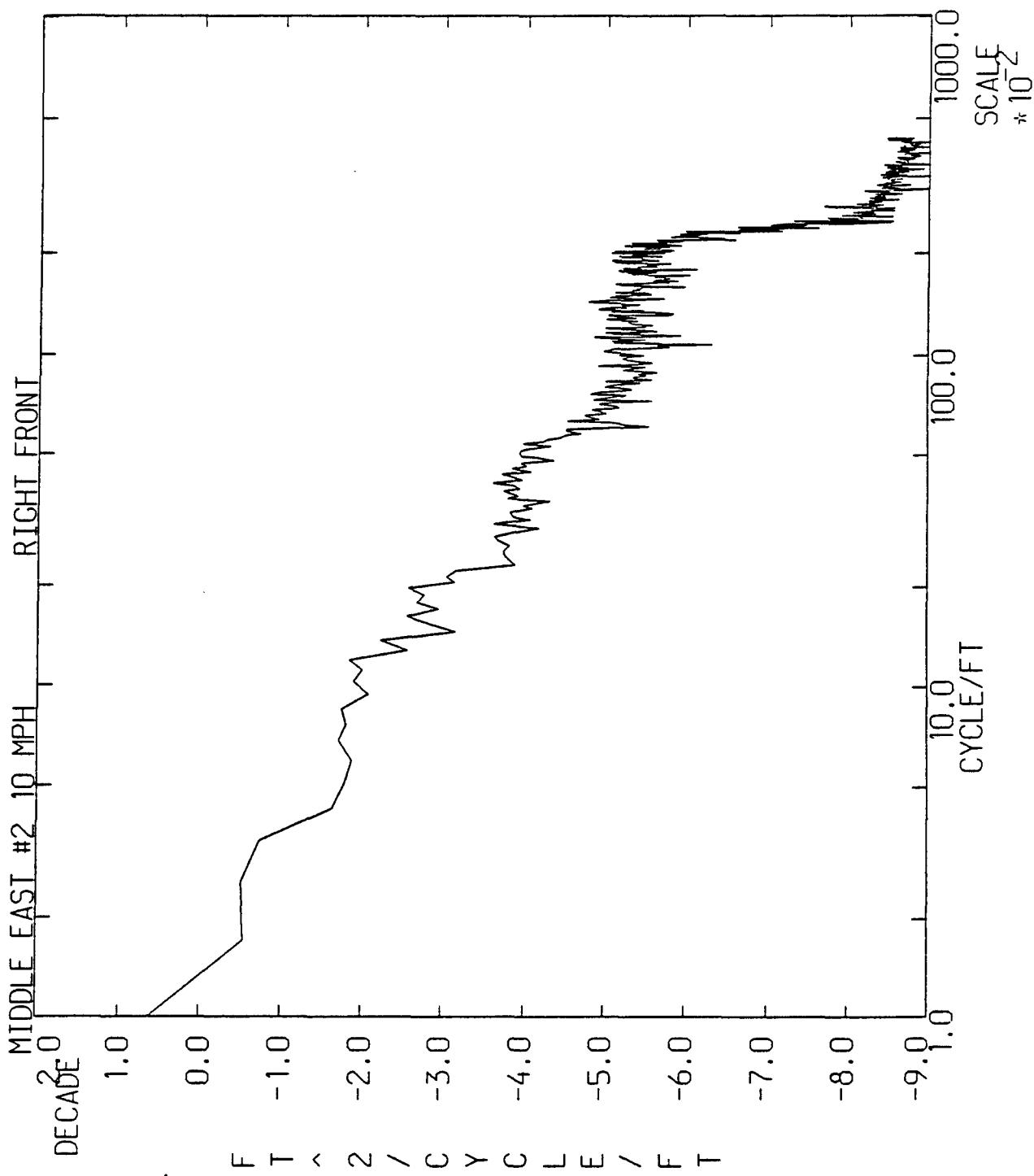


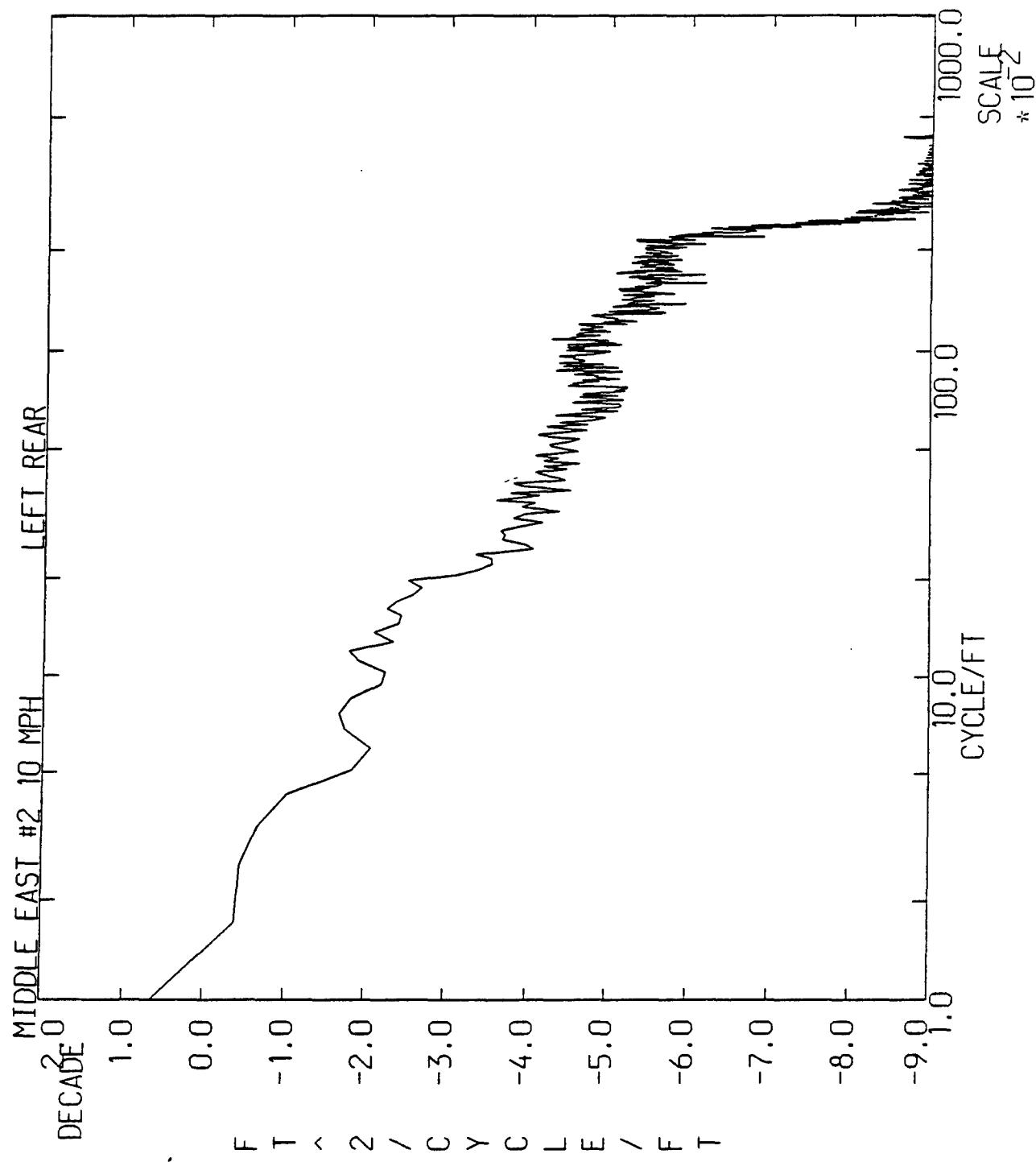


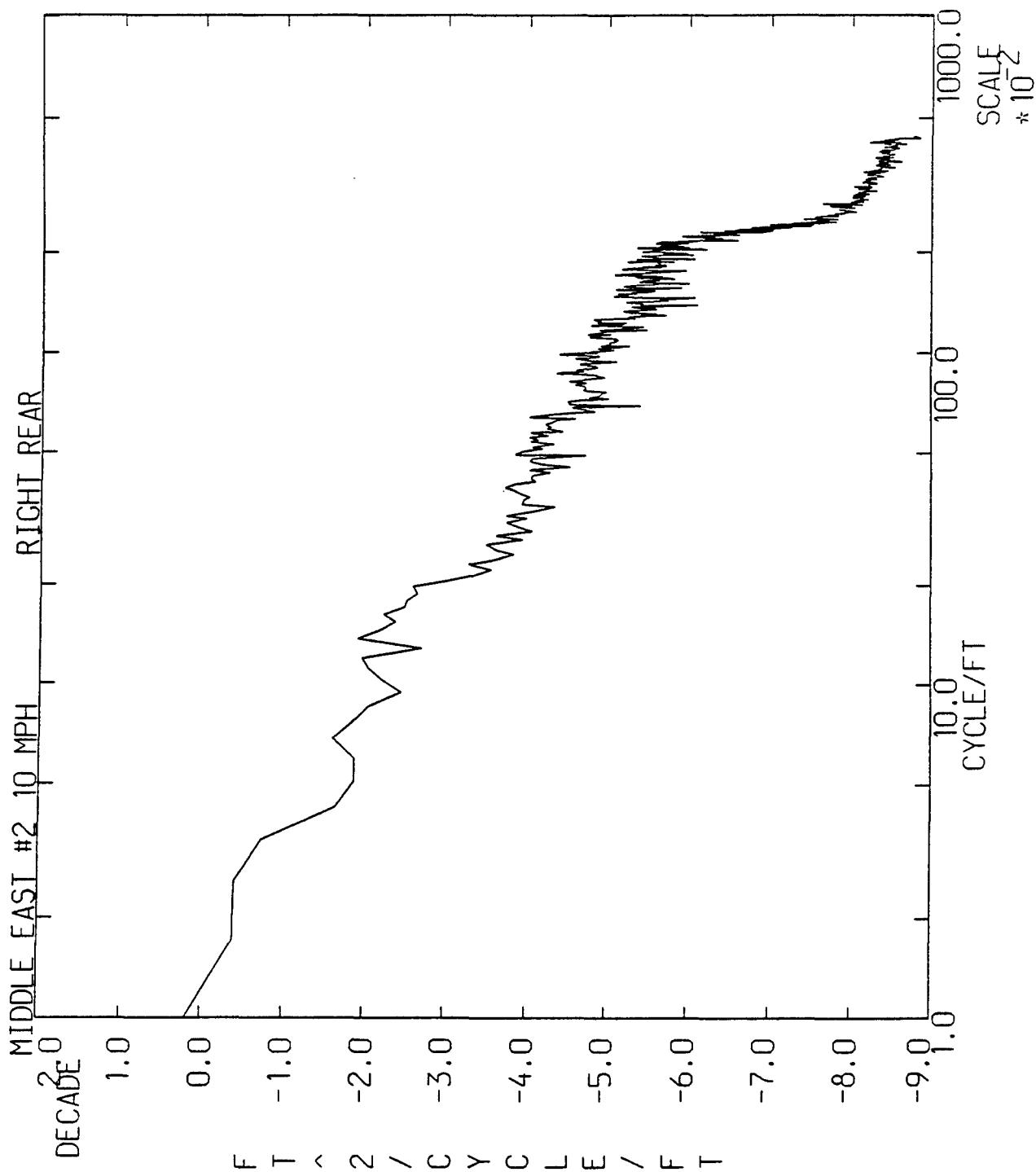












TRUCK HILL #1

WAVE-NUMBER SPECTRA

2, 4, 6, 8 and 10 MPH

Four (4) curves per speed, one for each DFMV tire, as follows

LEFT FRONT
RIGHT FRONT
LEFT REAR
RIGHT REAR

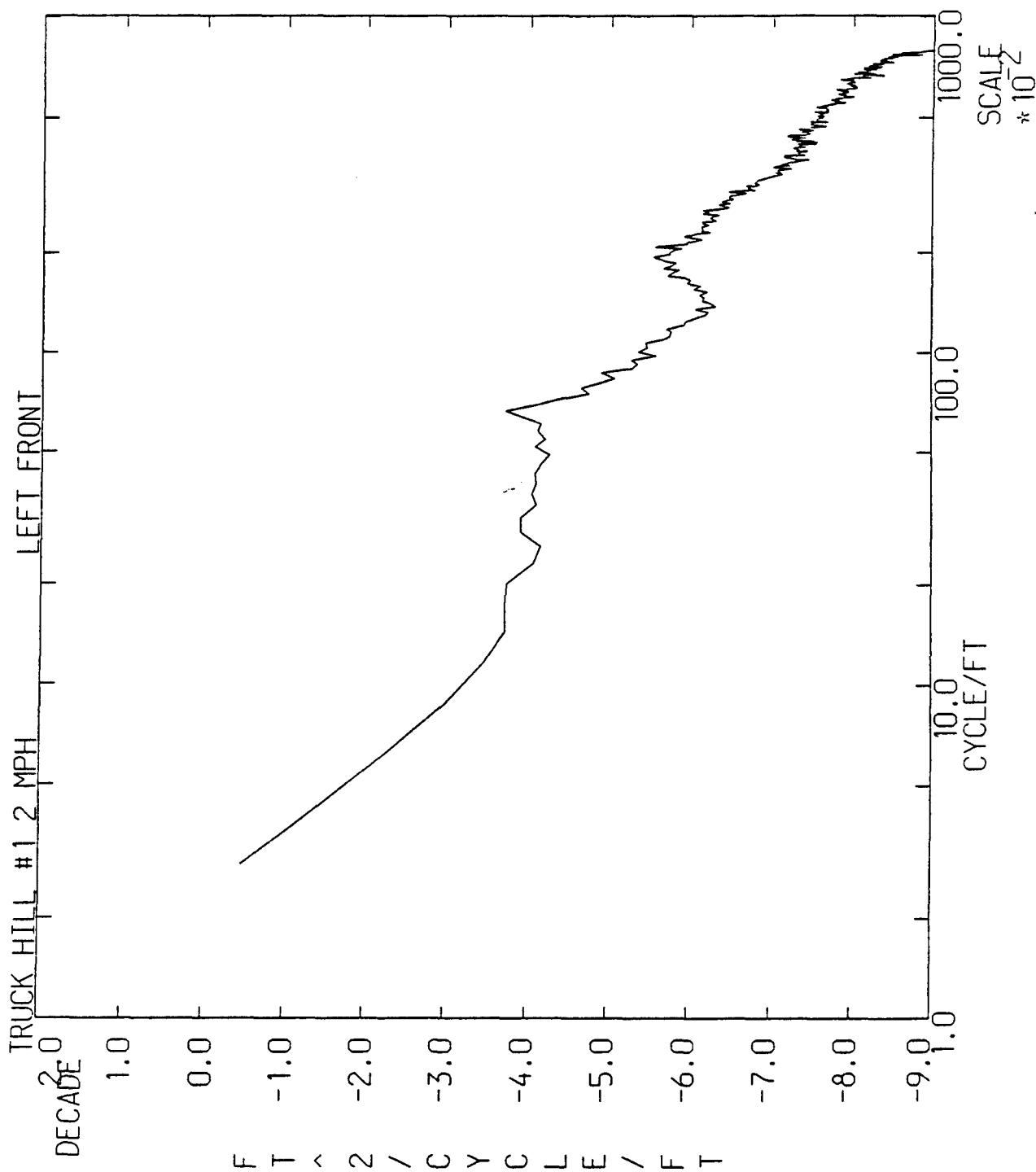
Volume II contains the data for the different DFMV speeds over each YPG course. The data was previously submitted to TACOM in an interim data report, however, the data was not reprocessed with the signal processing considerations discussed in the Volume I report (e.g., in this data, much of the spectral resolution was below the footprint). The wave-number cut-off at the low end of the spectra was limited by the frequency range of the accelerometer, as discussed in the report and shown in the table below. The wave-number cut-off at the high end of the spectrum was limited by the footprint length of the DFMV tire, which was ≈ 1.2 ft $^{-1}$. These cut-offs were verified through the DFMV front-to-rear coherence plots. Therefore, when comparing plots between different speeds, do not compare the data past these limits. As discussed in the report, the faster speed runs produced the best results at the lower wave numbers.

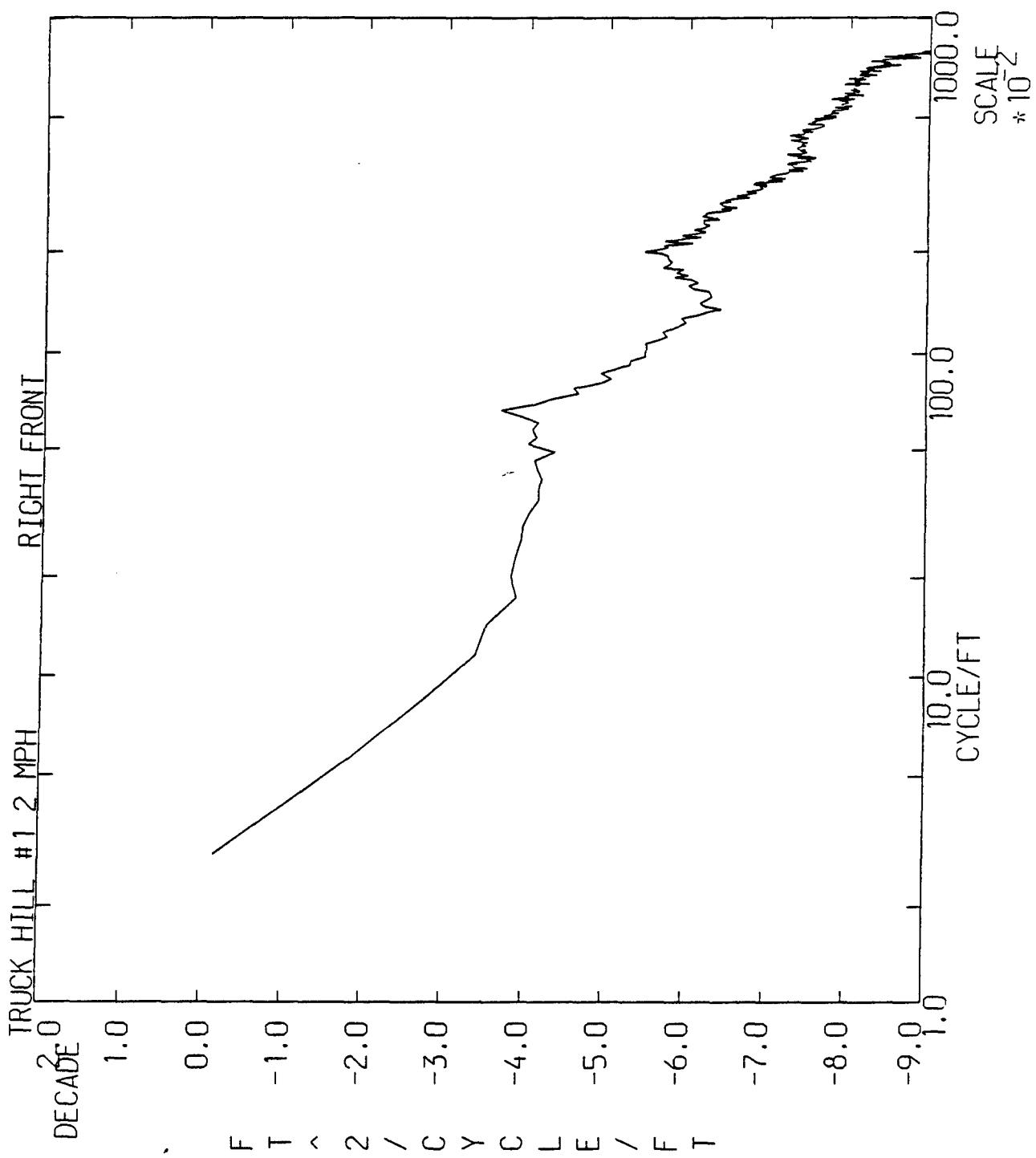
Table 1. DFMV Actual Versus Predicted Wavelength Limits

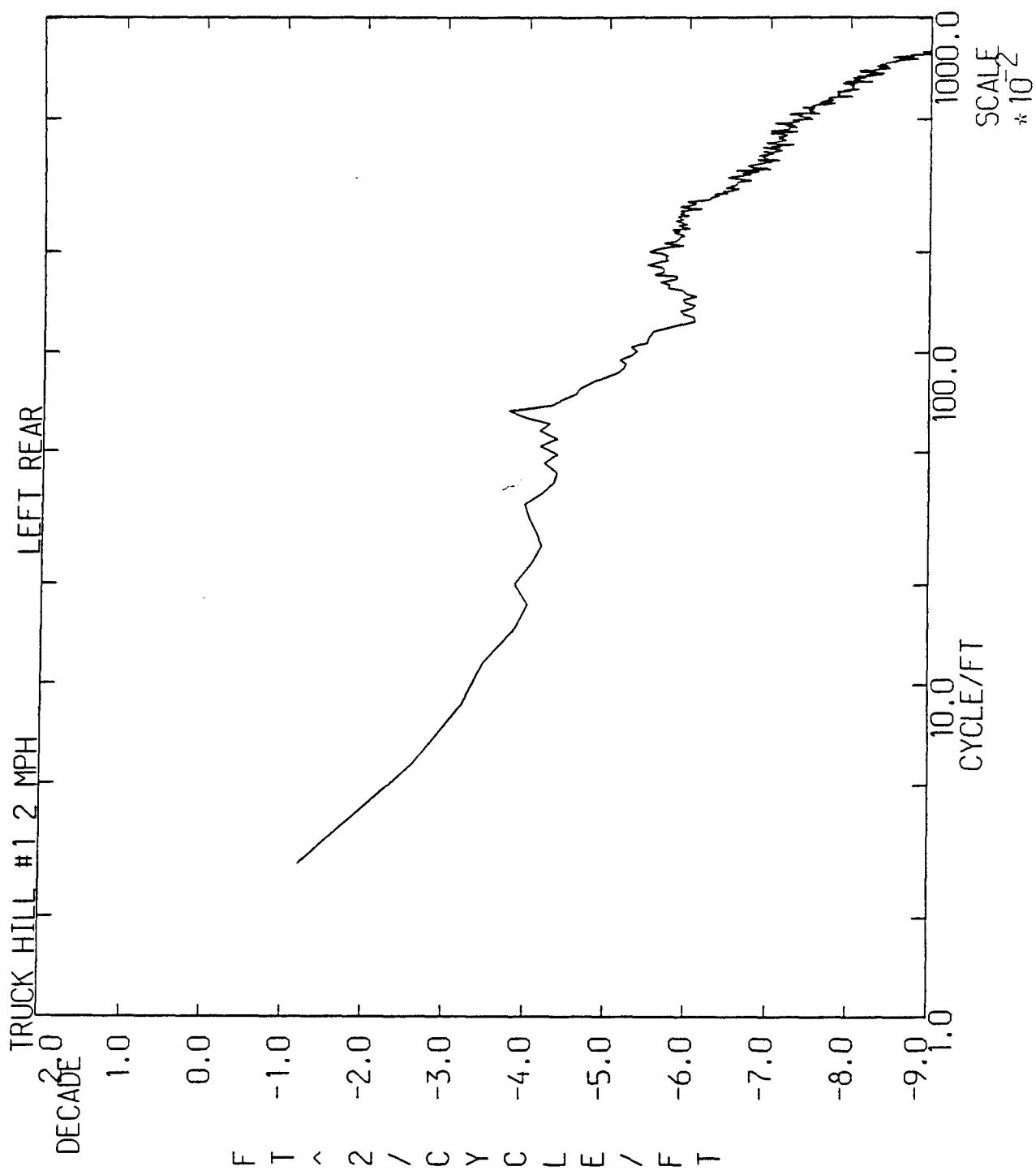
DFMV Speed MPH	Expected Wavelength Resolution*	Actual Wavelength Resolution**
2	60	15
4	120	30
6	180	45
8	240	60
10	300	75

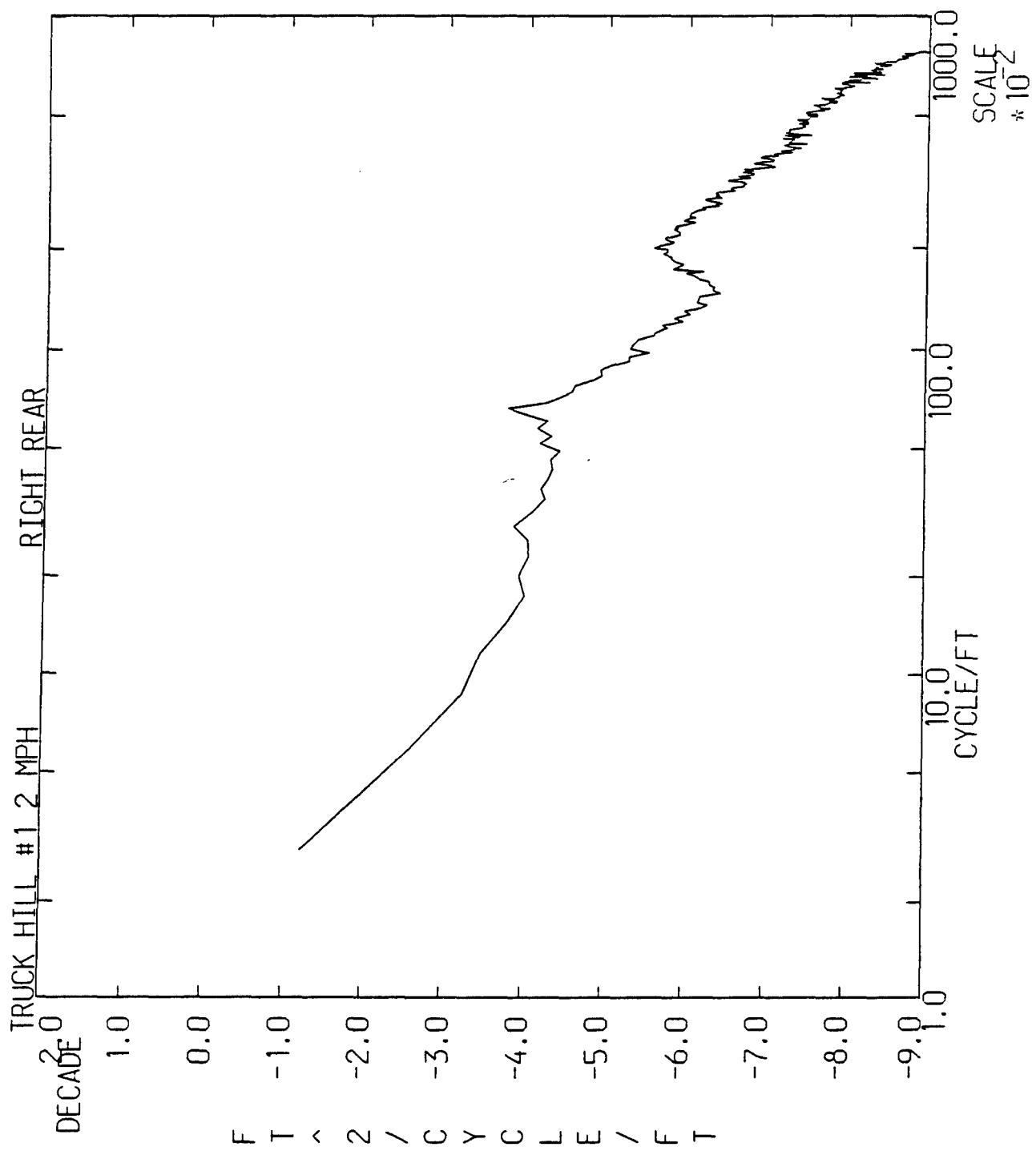
* Based on the advertised low-end frequency range for the accelerometer used

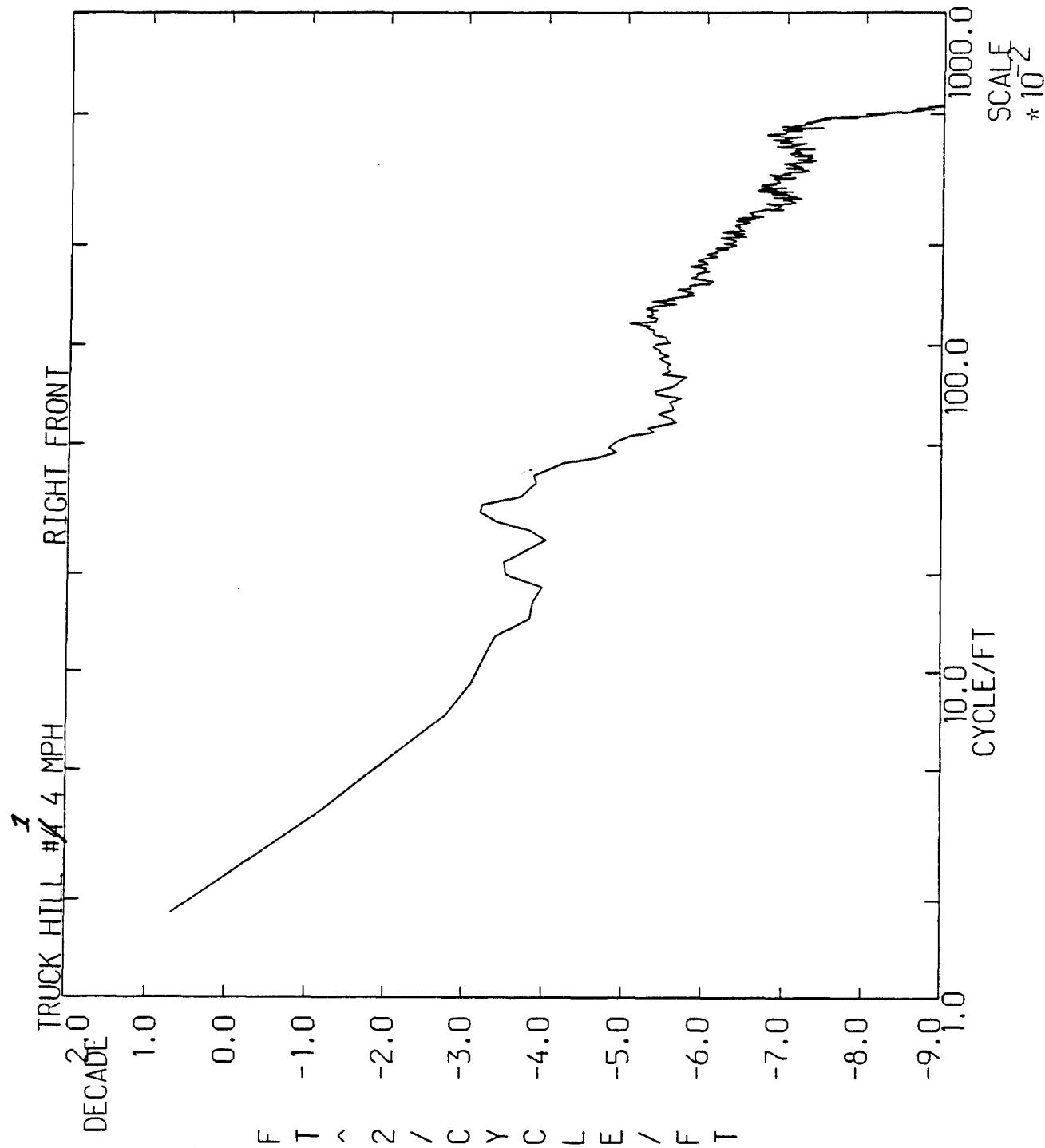
** Based on actual low-end frequency range for the accelerometer used

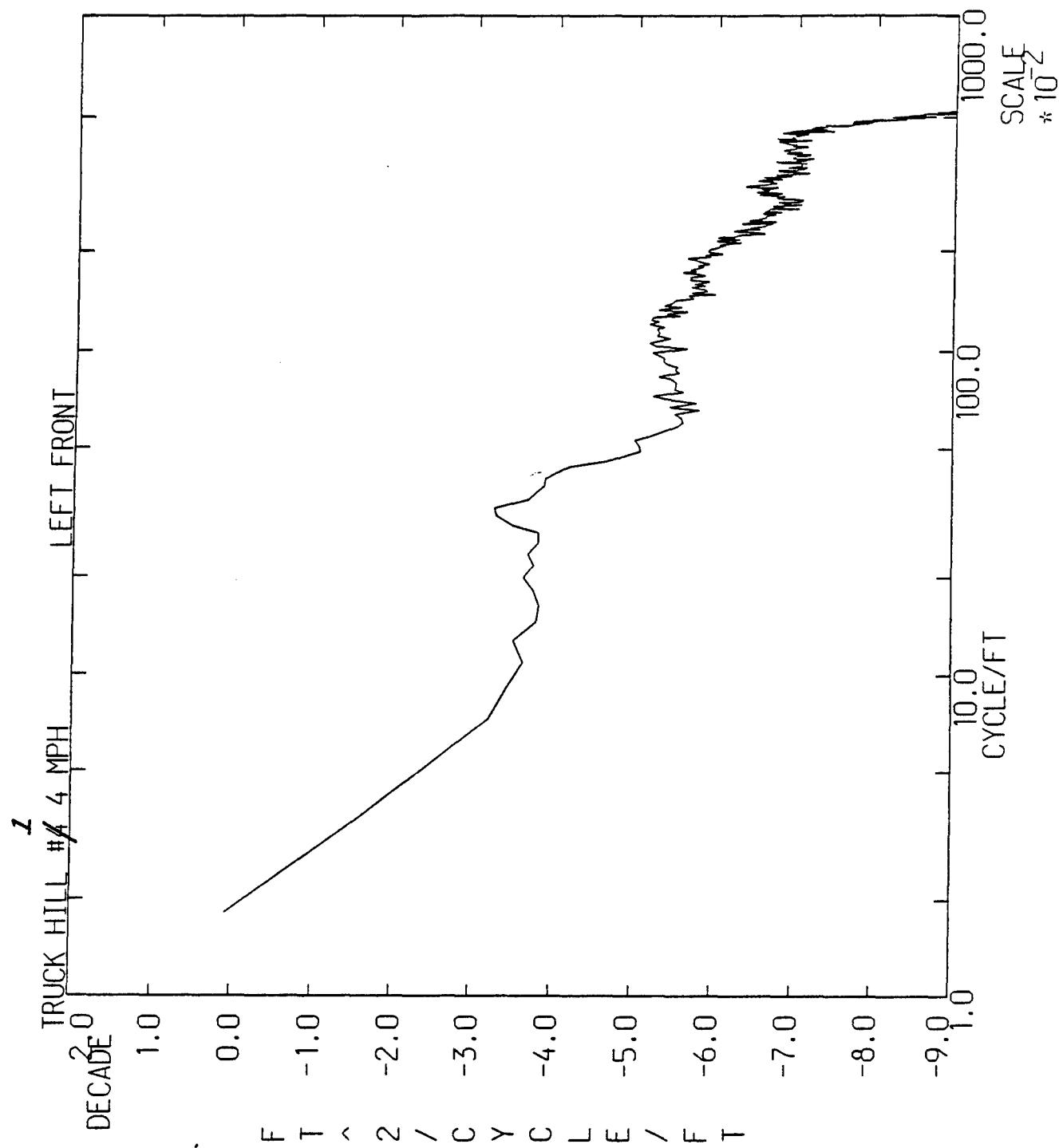


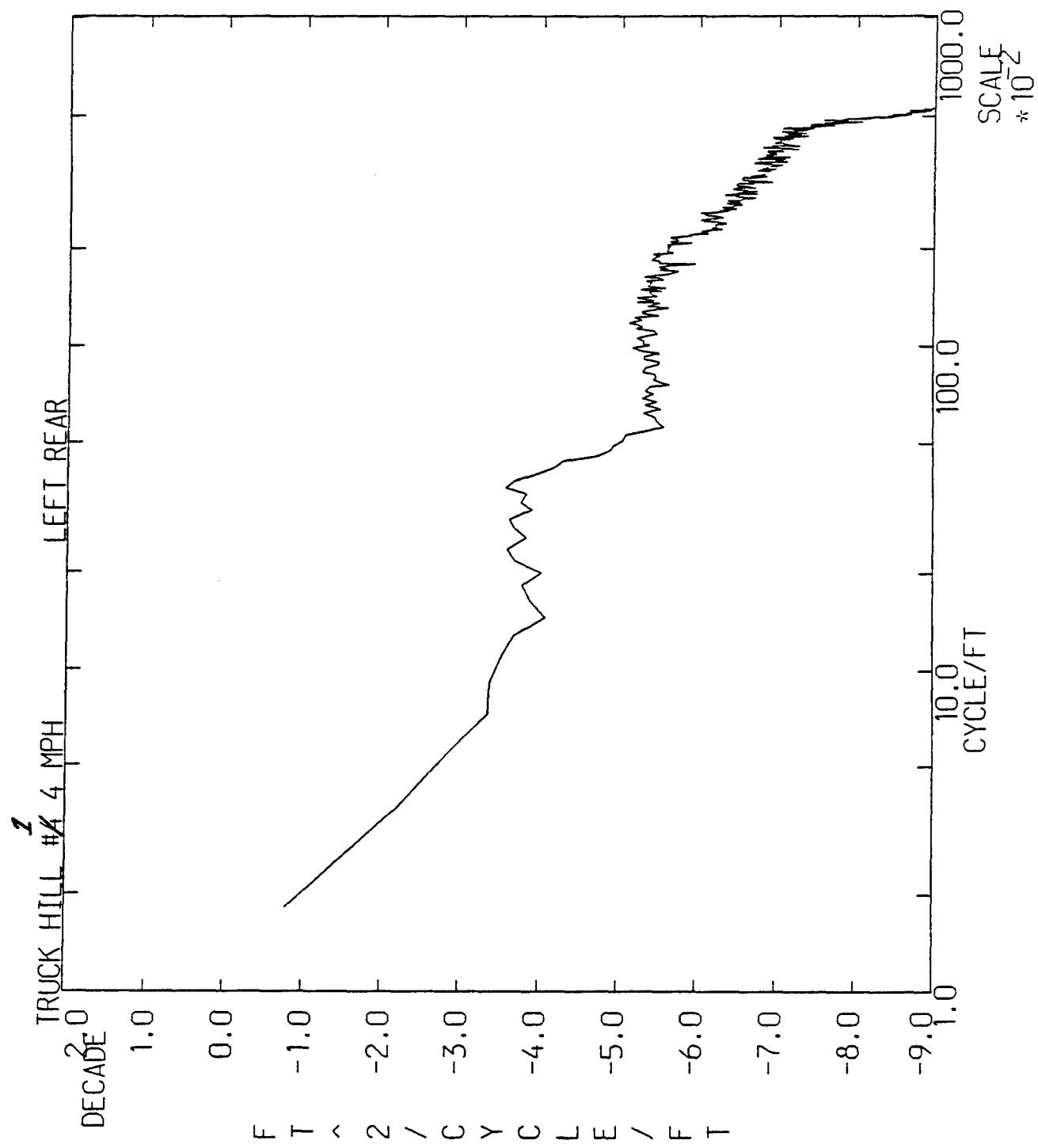


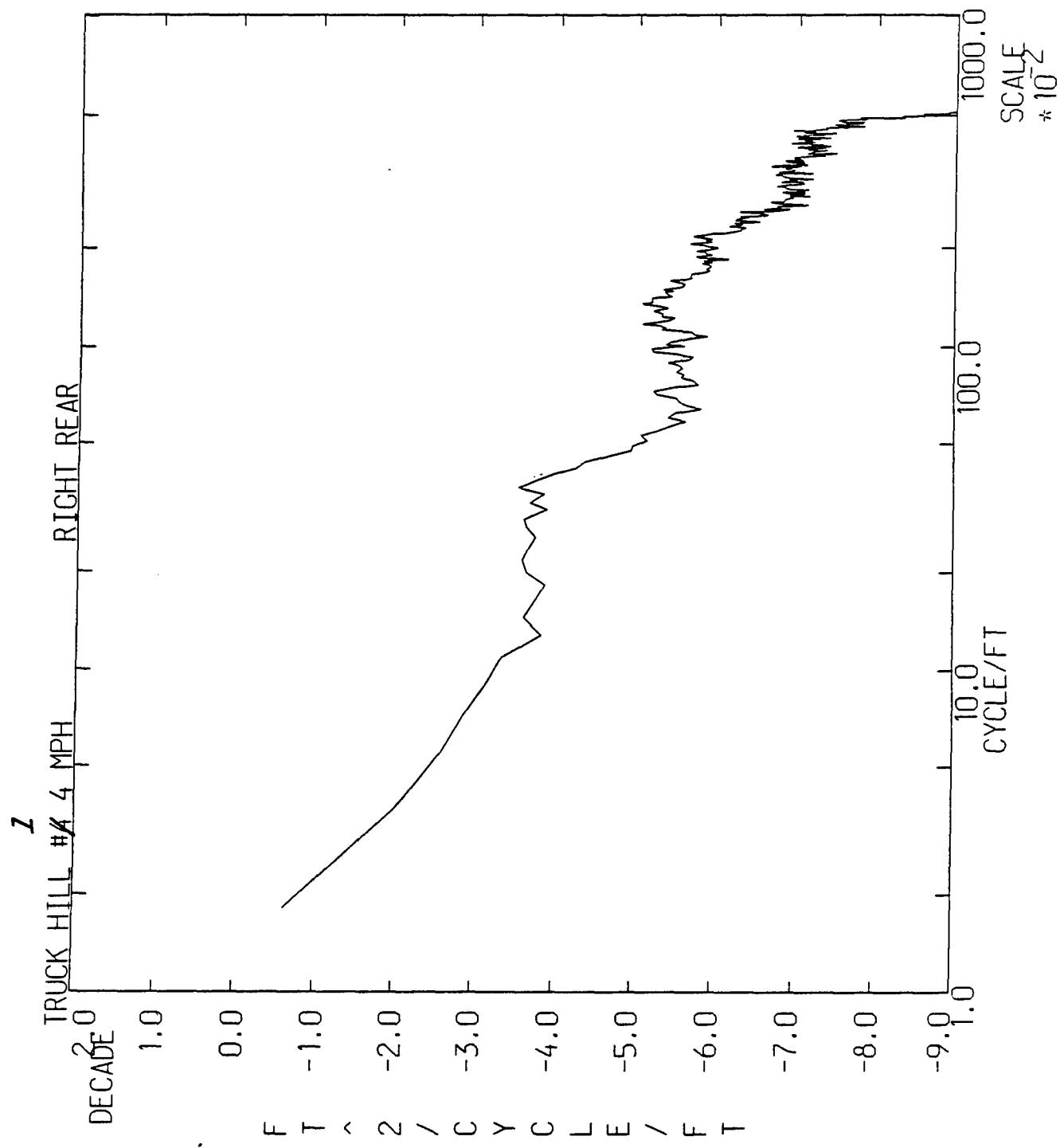


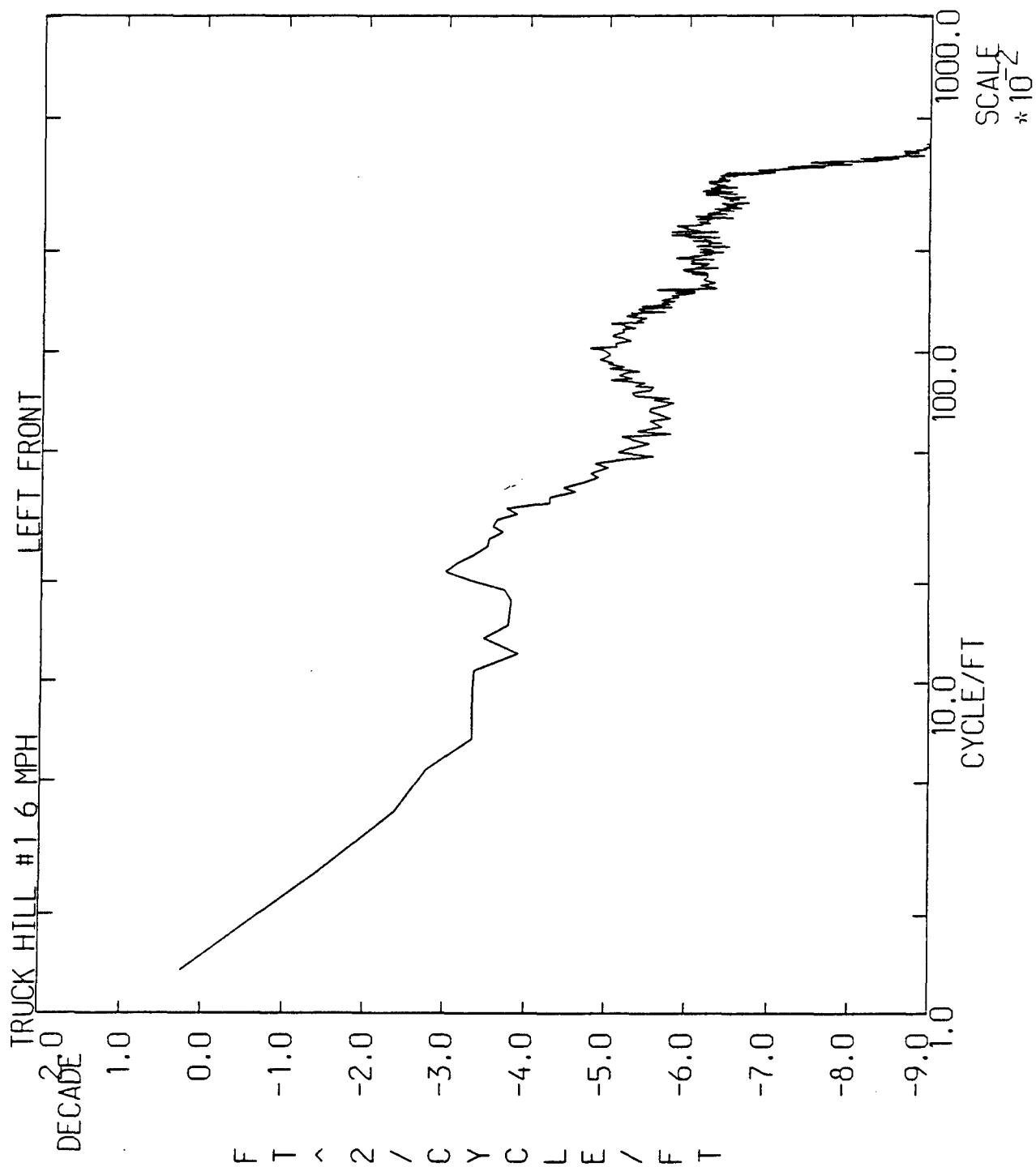


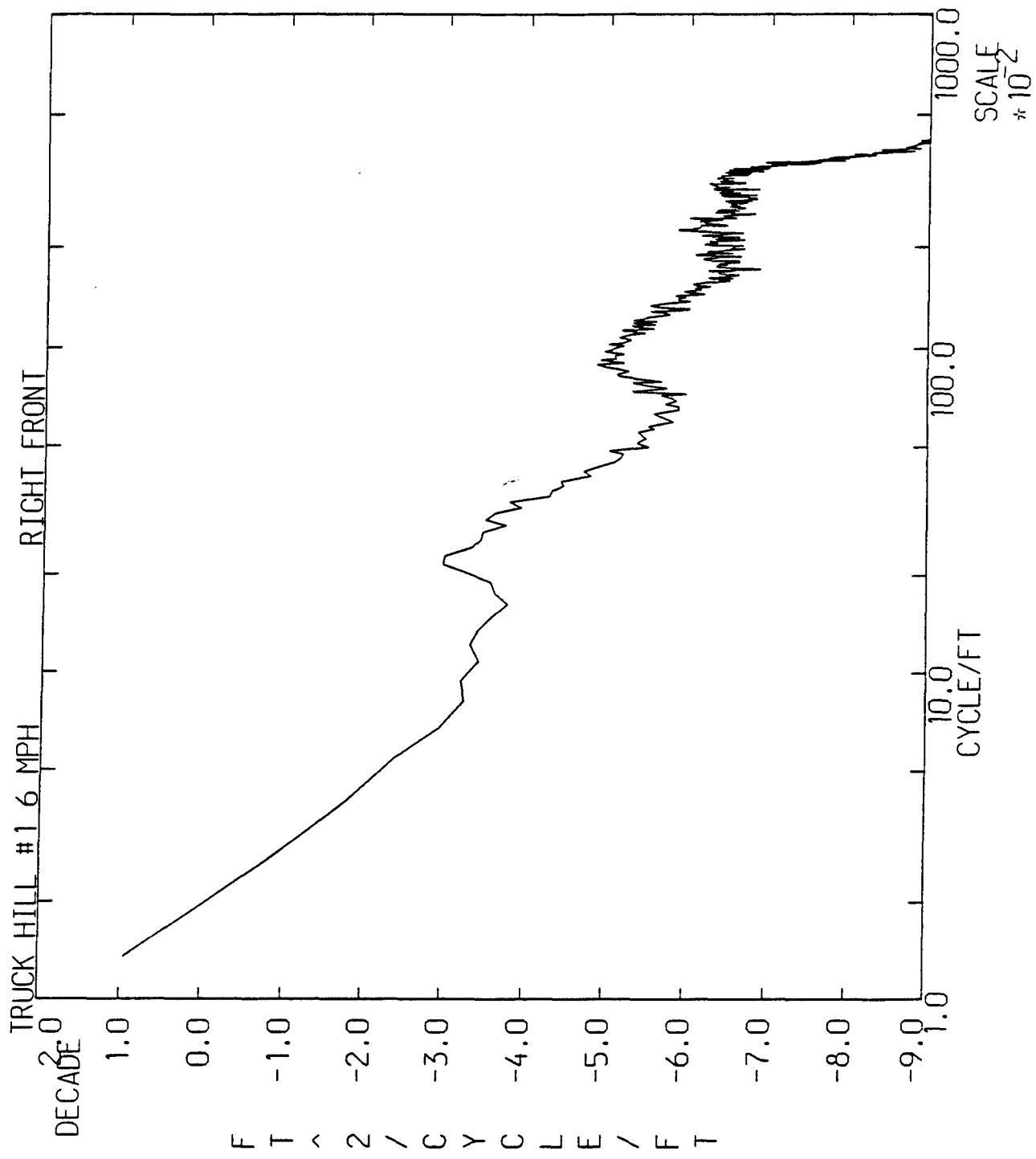


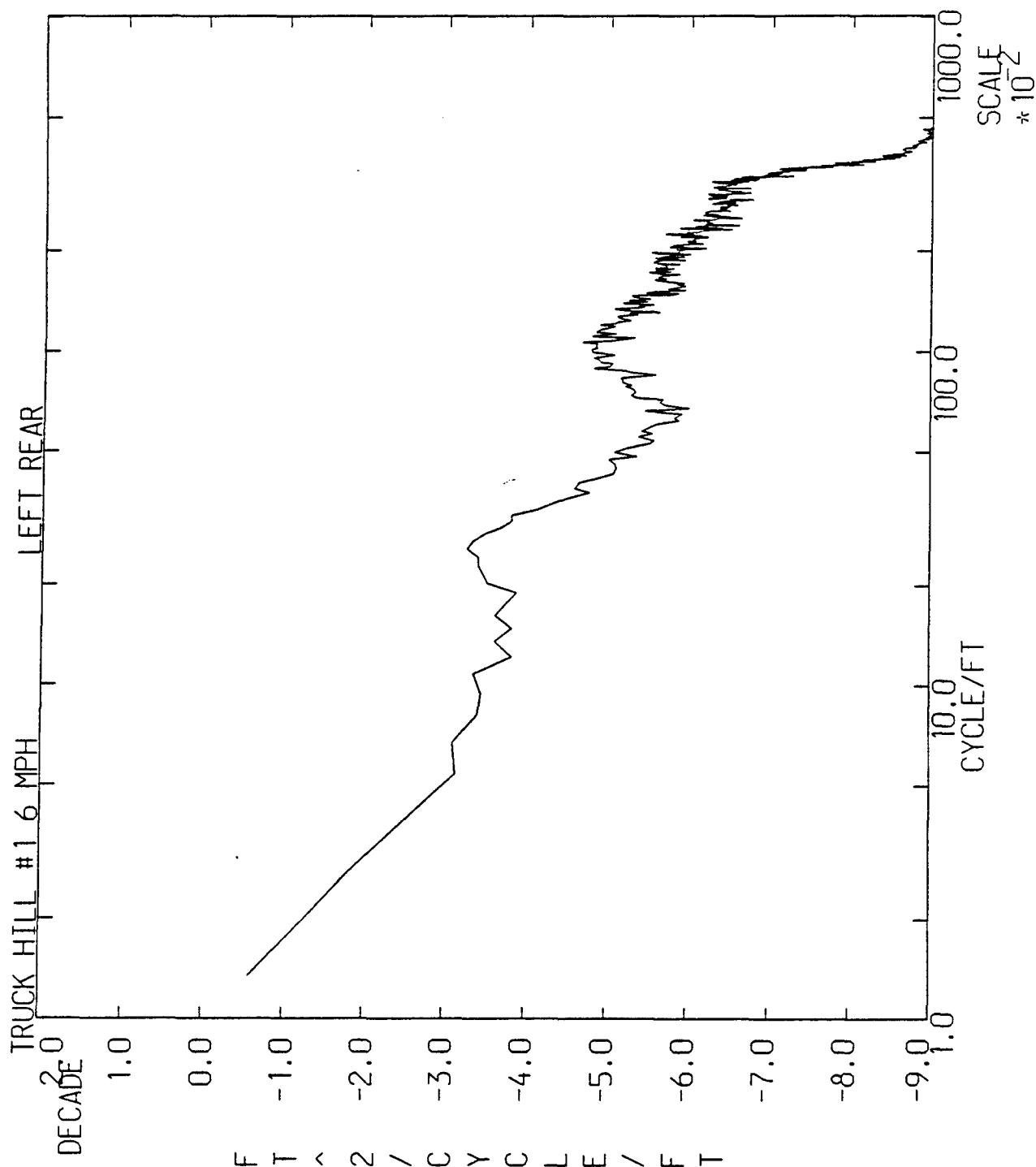


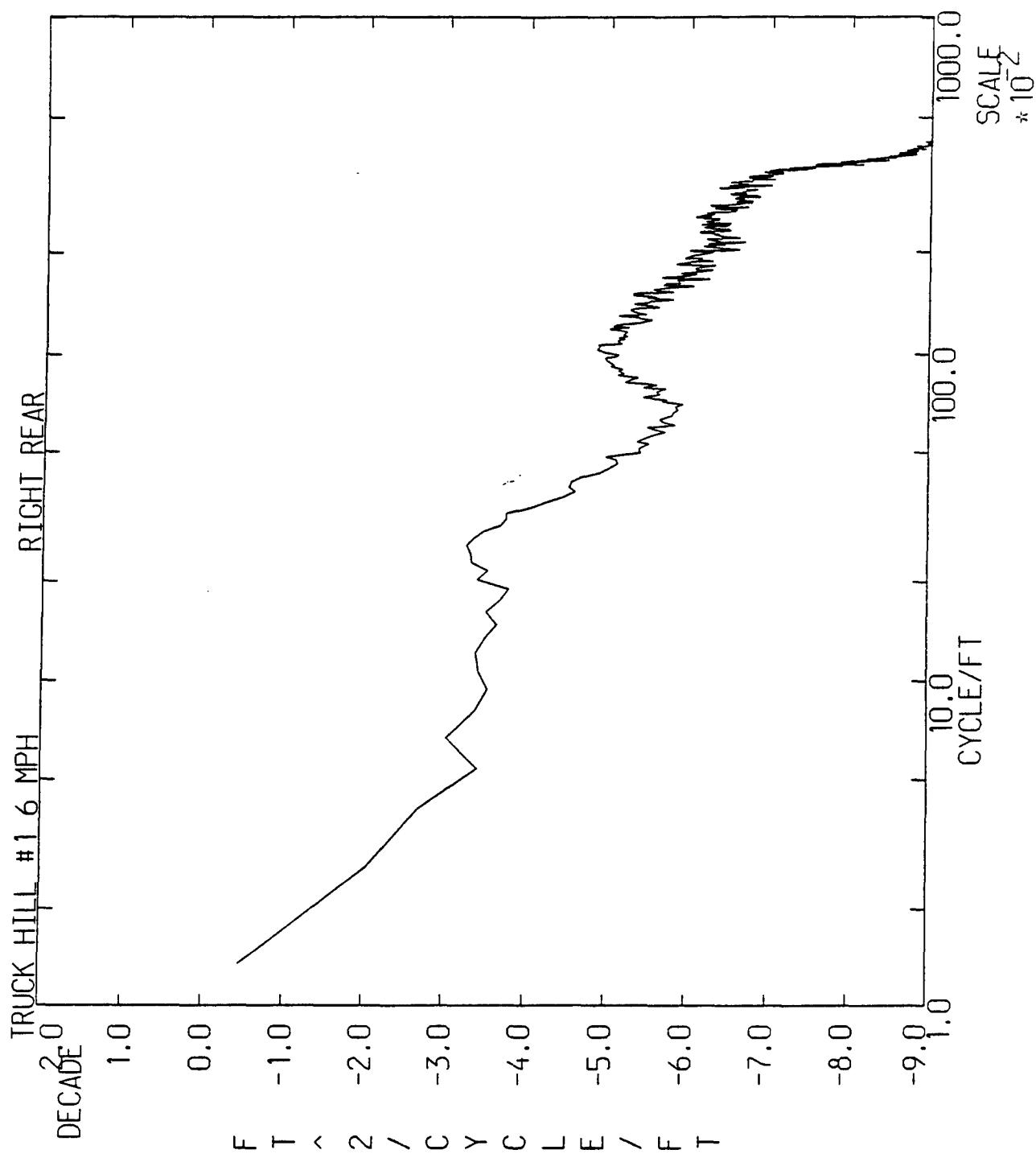


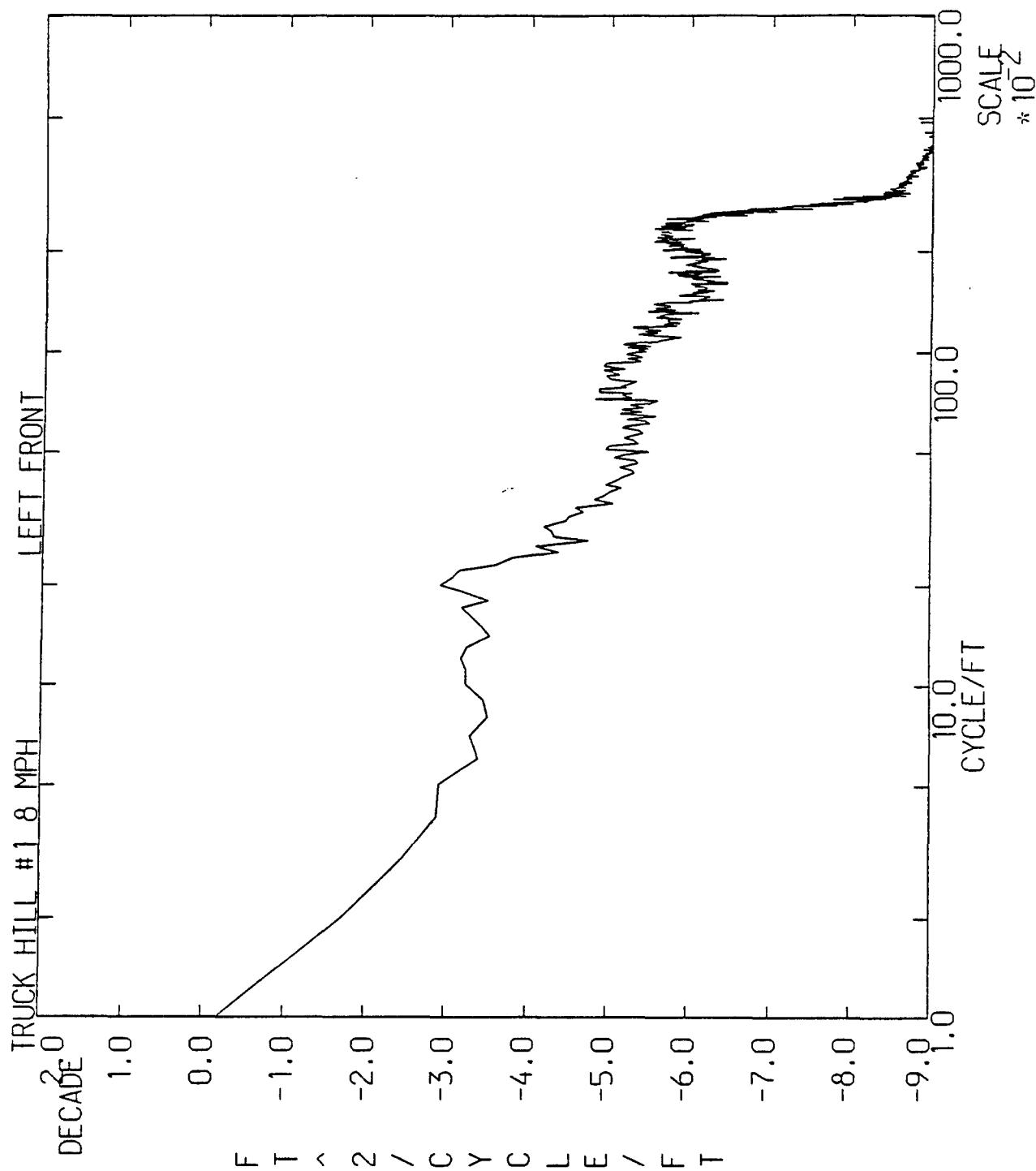


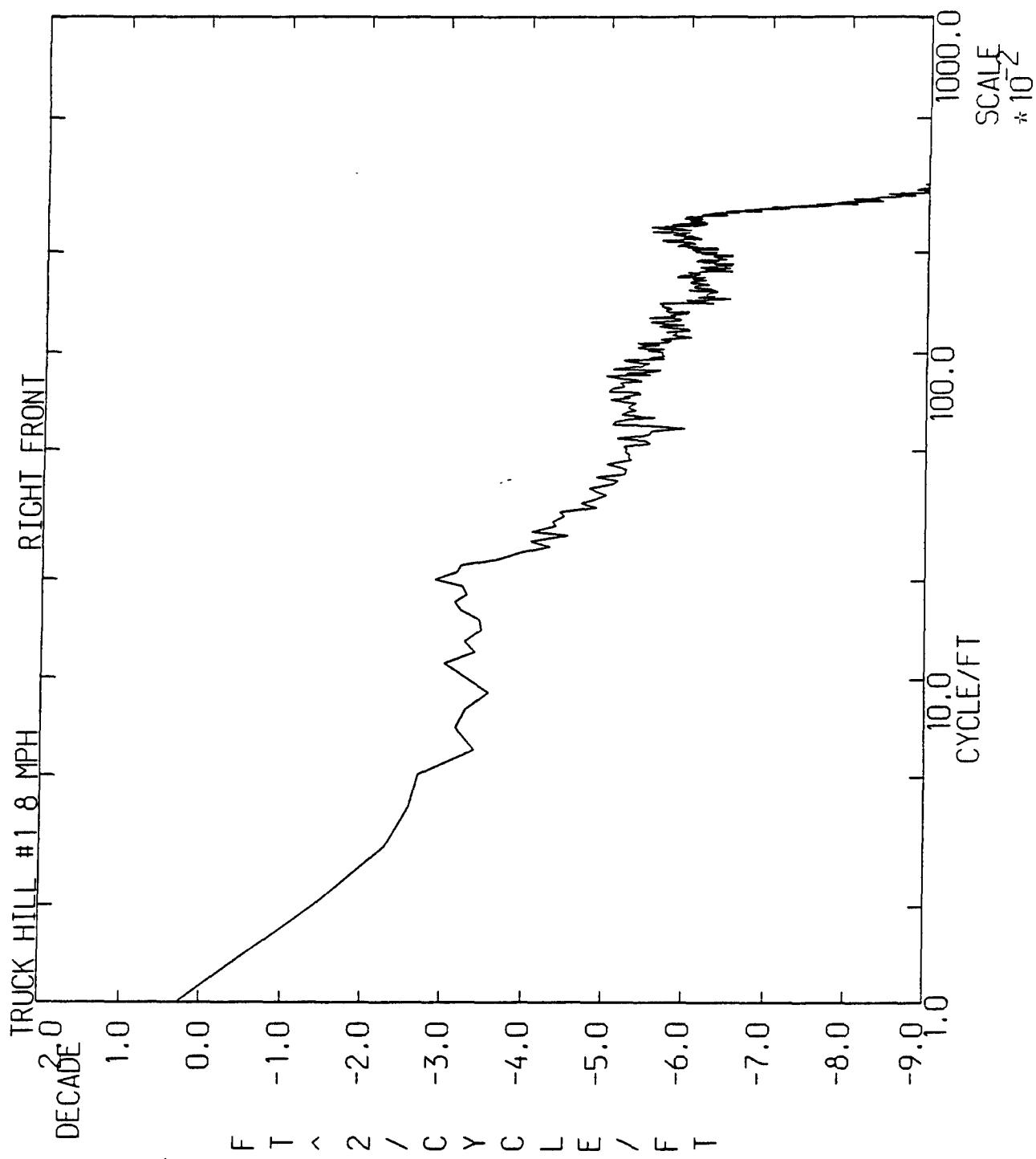


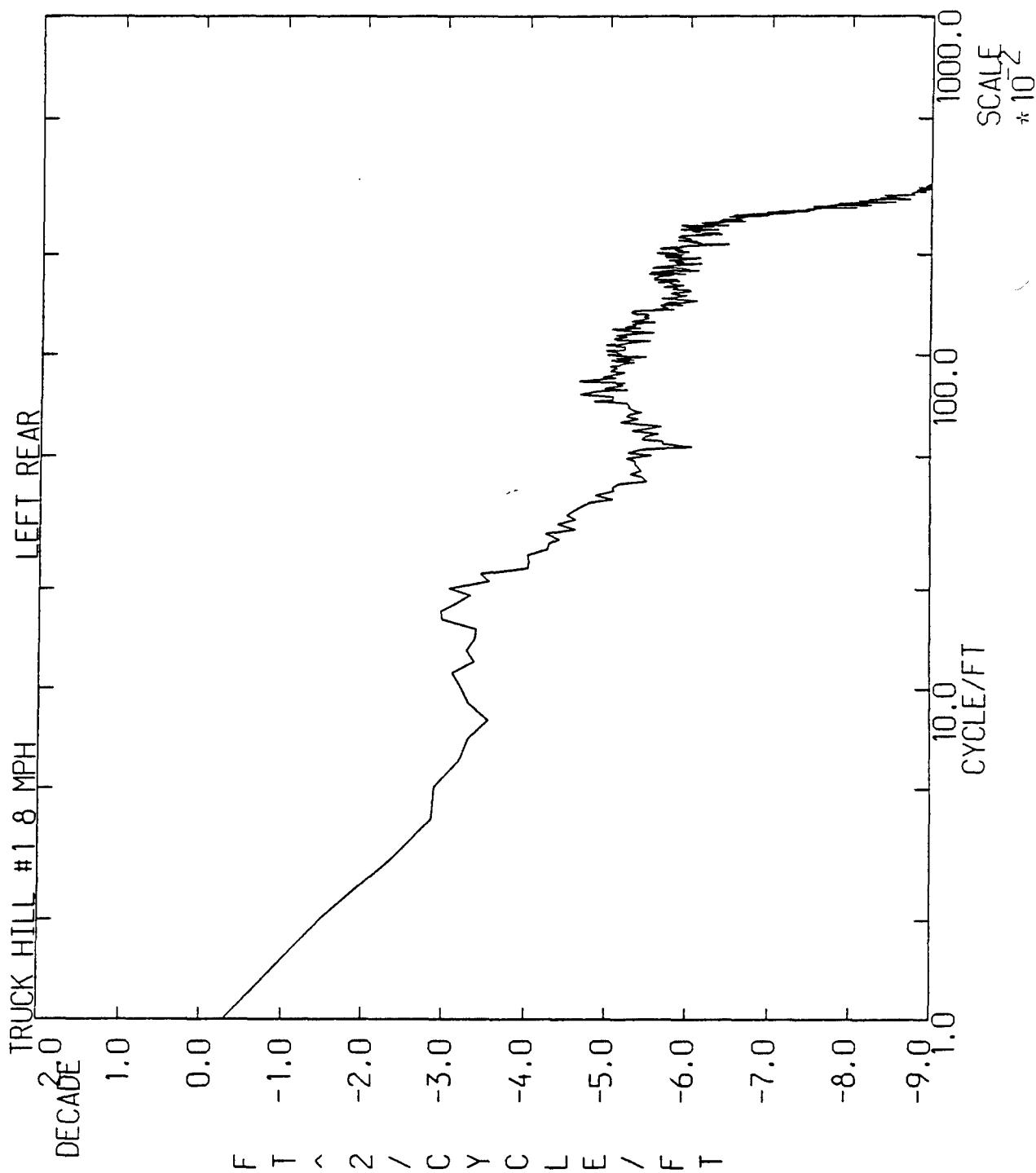


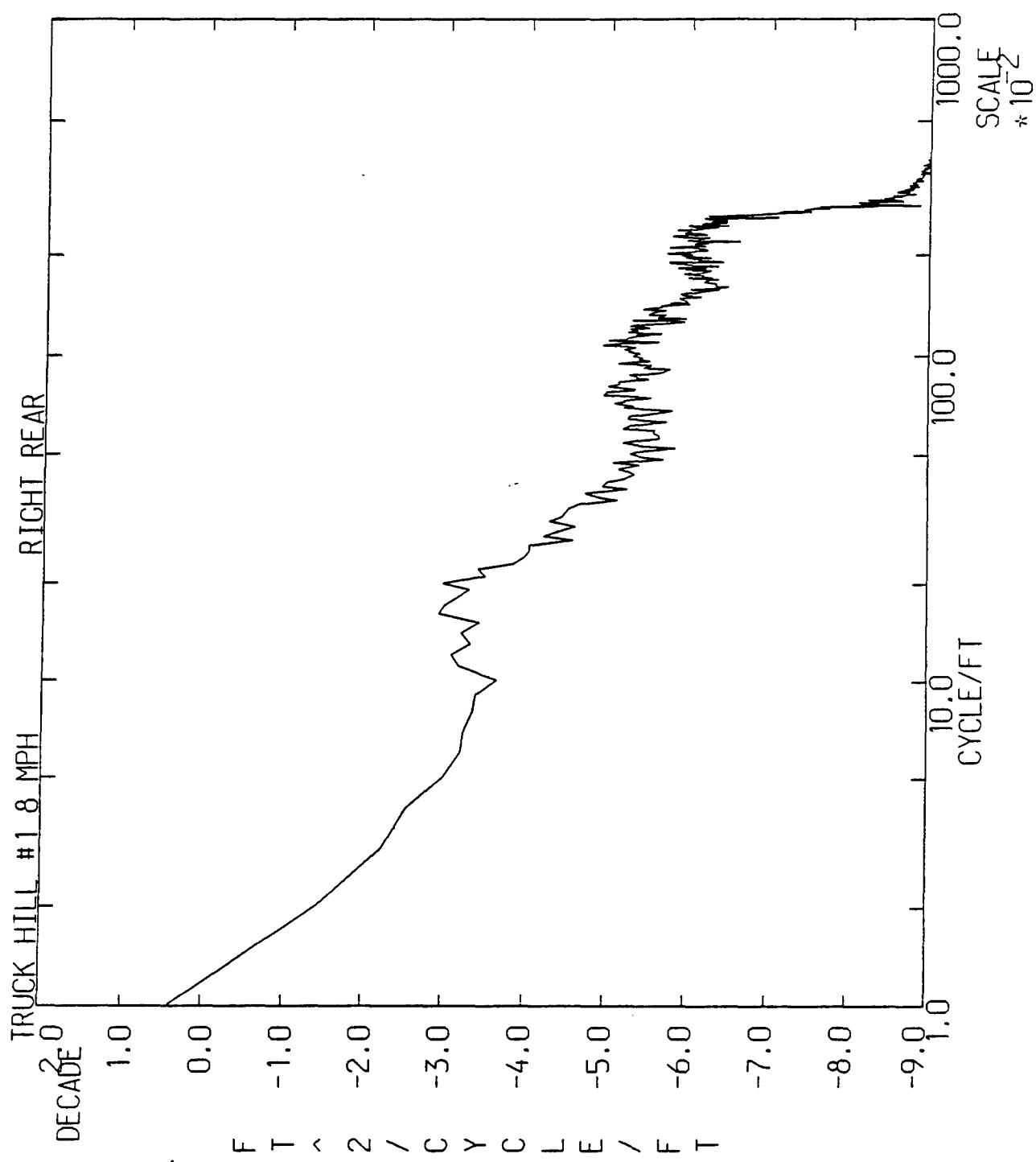


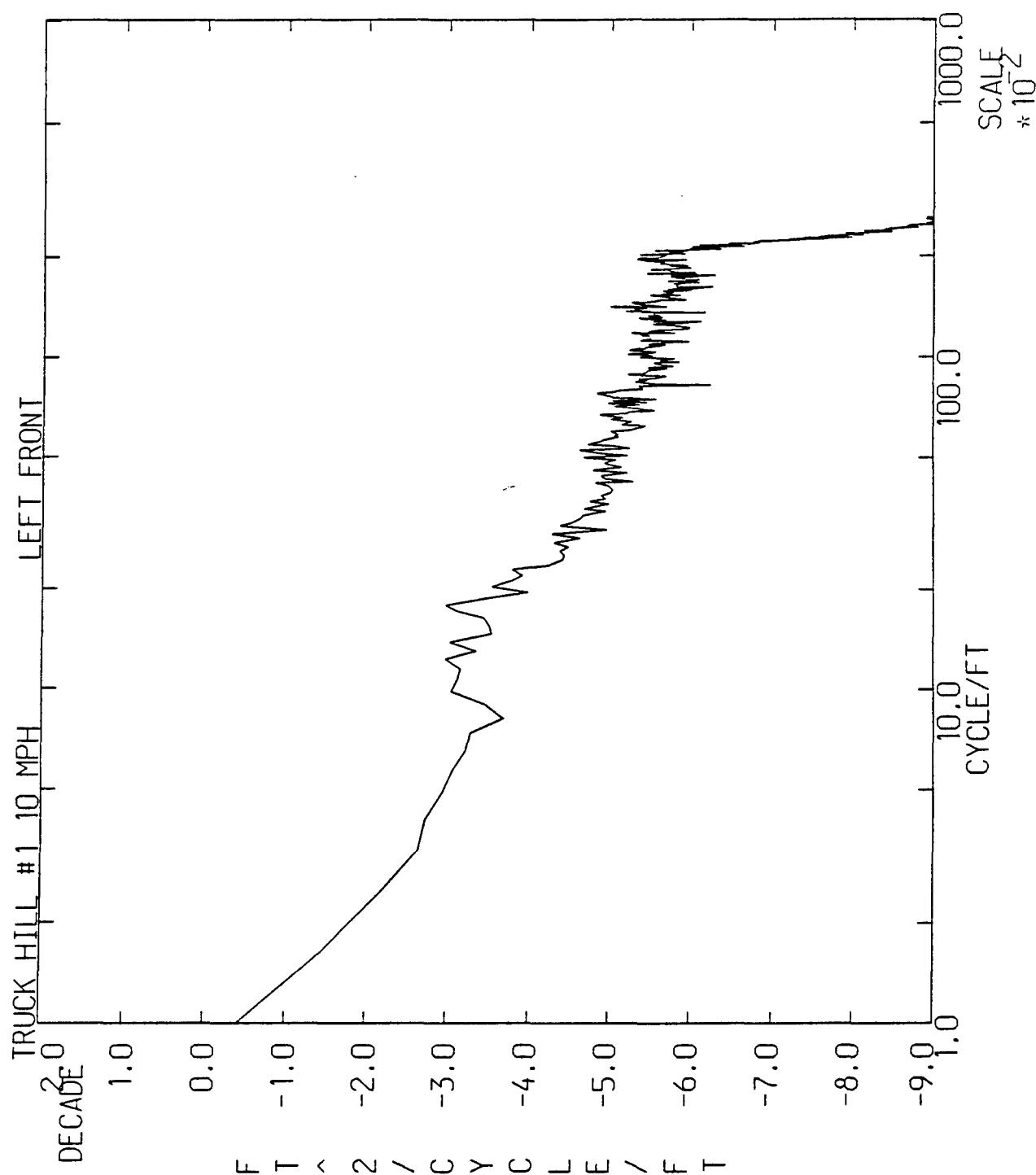


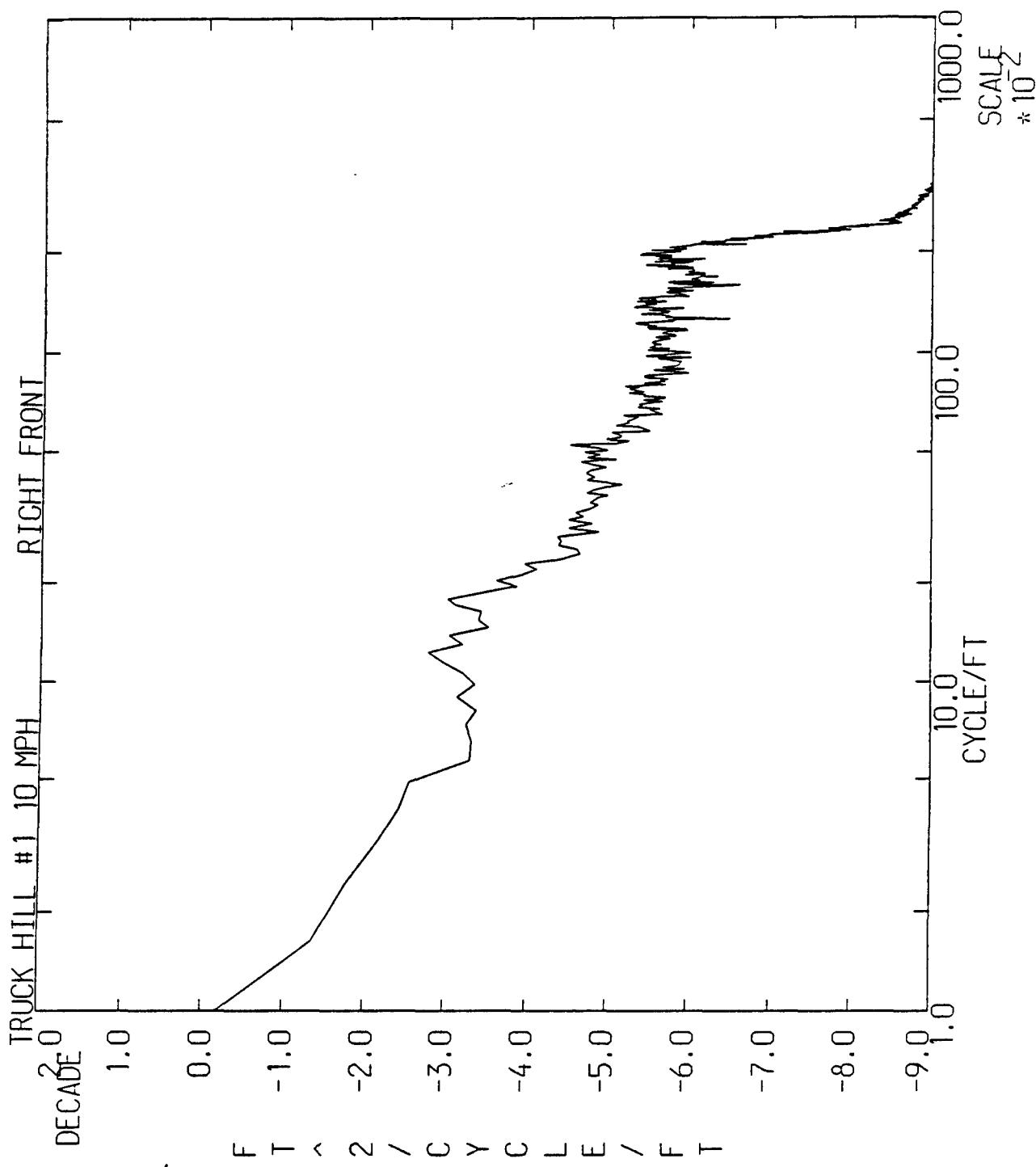


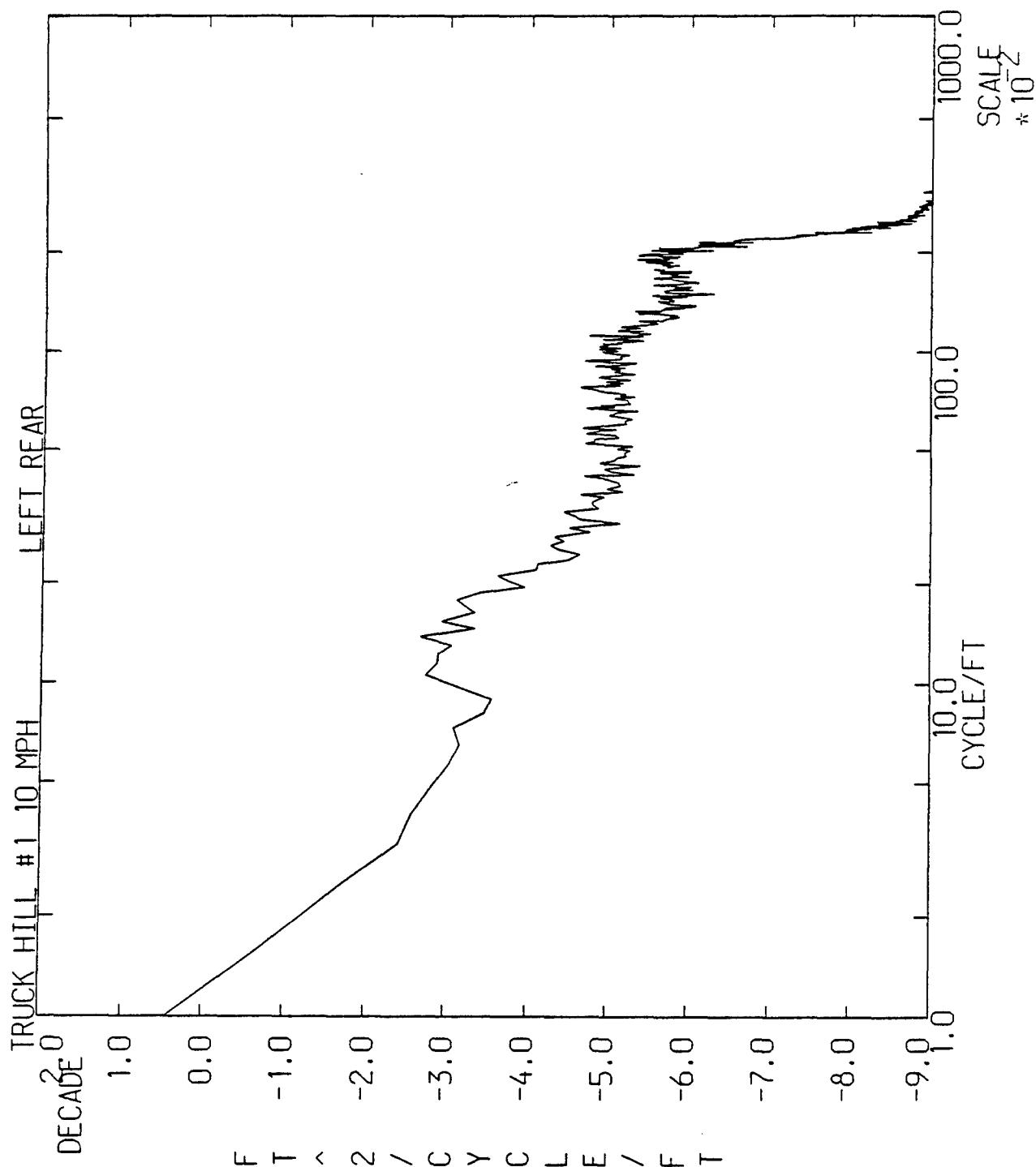


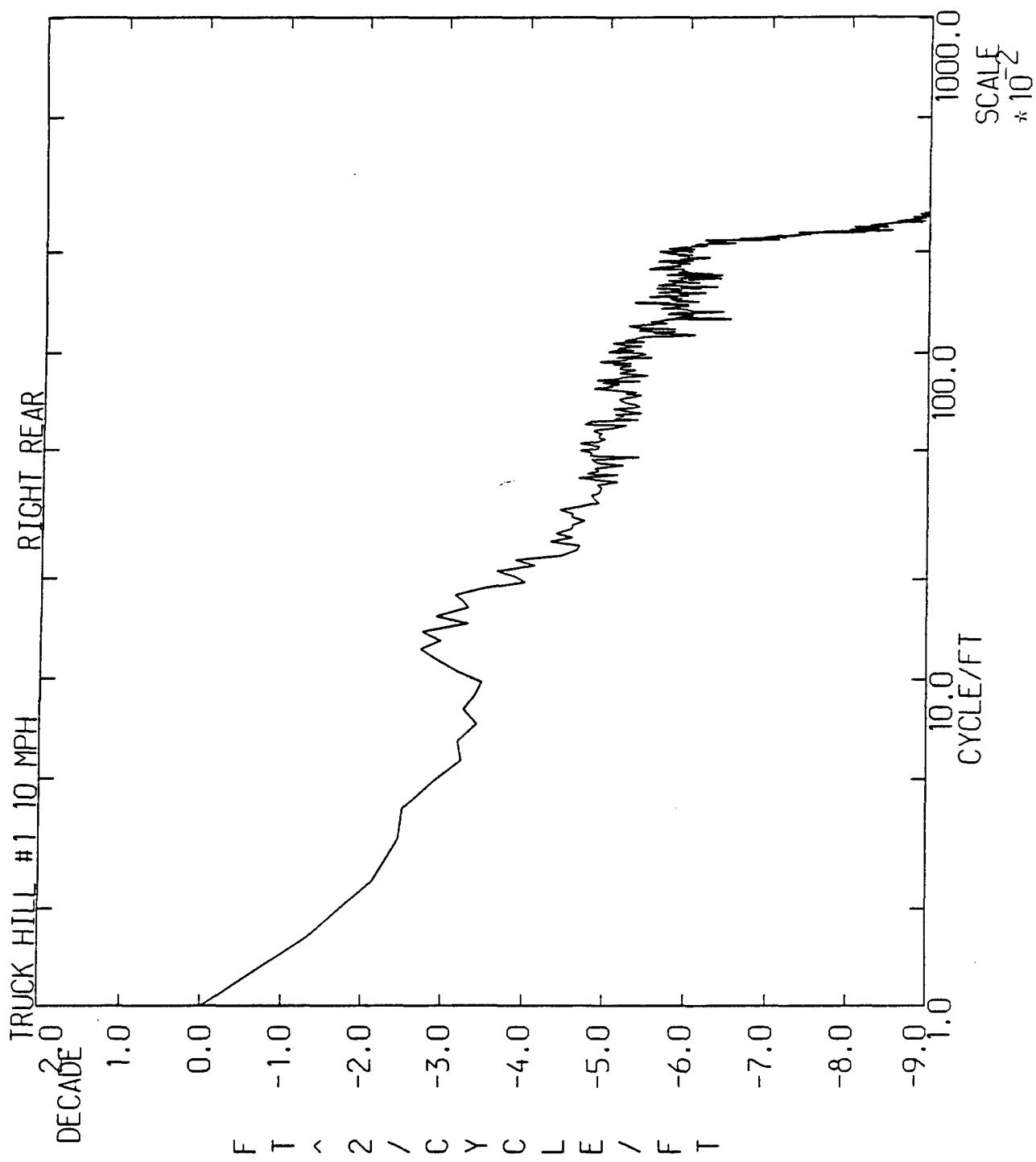












TRUCK HILL #2

WAVE-NUMBER SPECTRA

4, 6, 8 and 10 MPH
(wrong sensitivity on 2 mph run)

Four (4) curves per speed, one for each DFMV tire, as follows

LEFT FRONT
RIGHT FRONT
LEFT REAR
RIGHT REAR

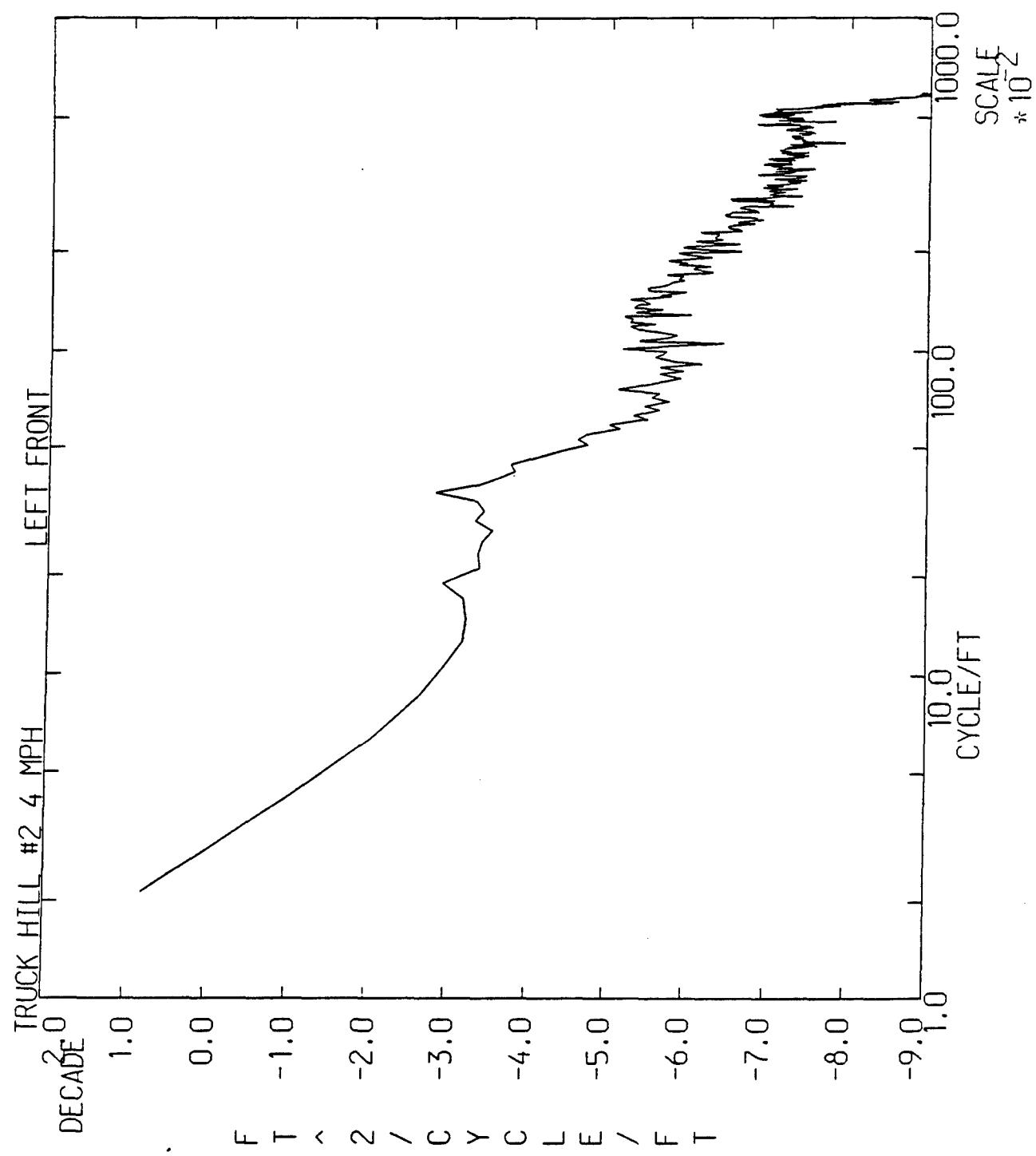
Volume II contains the data for the different DFMV speeds over each YPG course. The data was previously submitted to TACOM in an interim data report, however, the data was not reprocessed with the signal processing considerations discussed in the Volume I report (e.g., in this data, much of the spectral resolution was below the footprint). The wave-number cut-off at the low end of the spectra was limited by the frequency range of the accelerometer, as discussed in the report and shown in the table below. The wave-number cut-off at the high end of the spectrum was limited by the footprint length of the DFMV tire, which was $\approx 1.2 \text{ ft}^{-1}$. These cut-offs were verified through the DFMV front-to-rear coherence plots. Therefore, when comparing plots between different speeds, do not compare the data past these limits. As discussed in the report, the faster speed runs produced the best results at the lower wave numbers.

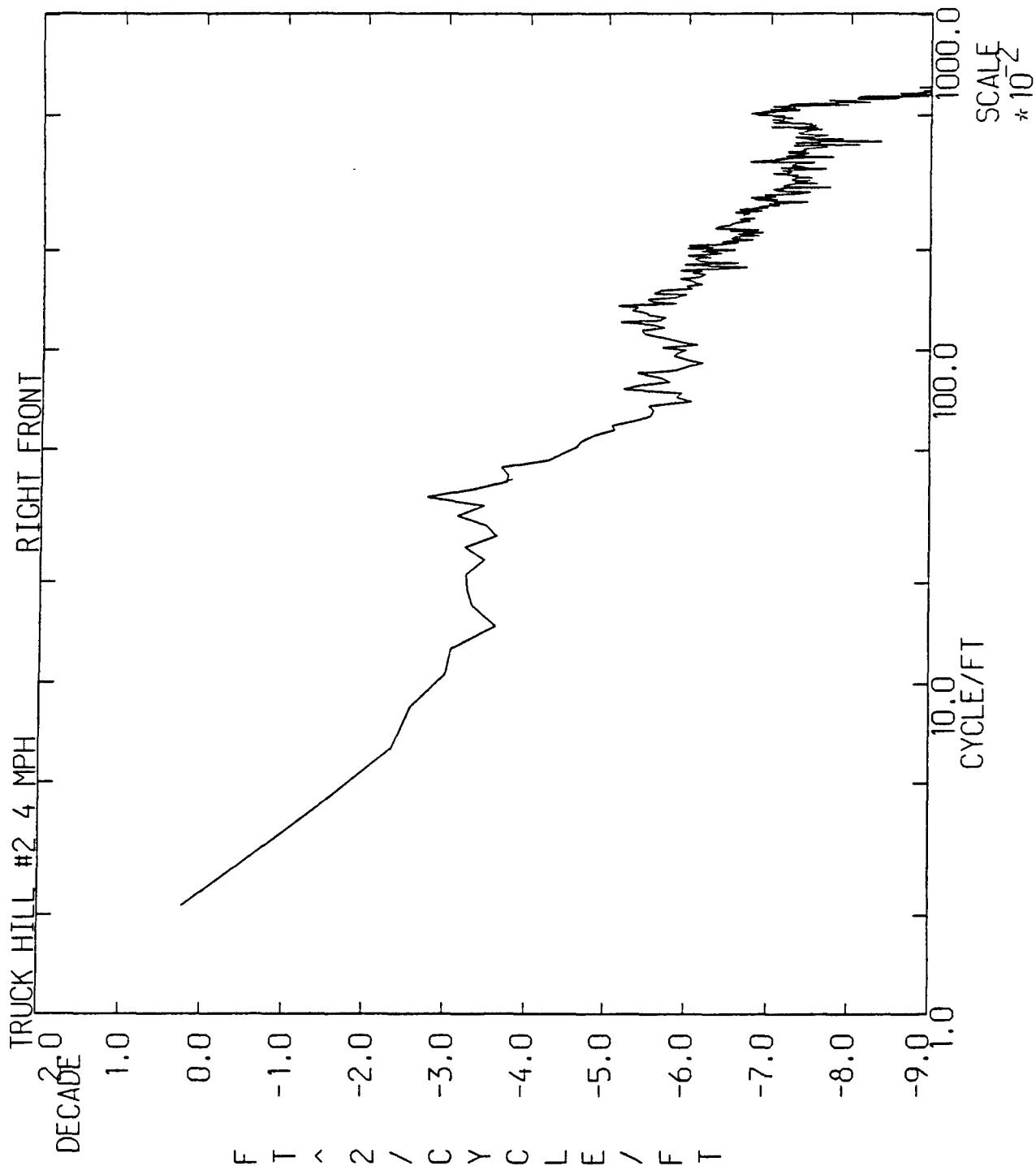
Table 1. DFMV Actual Versus Predicted Wavelength Limits

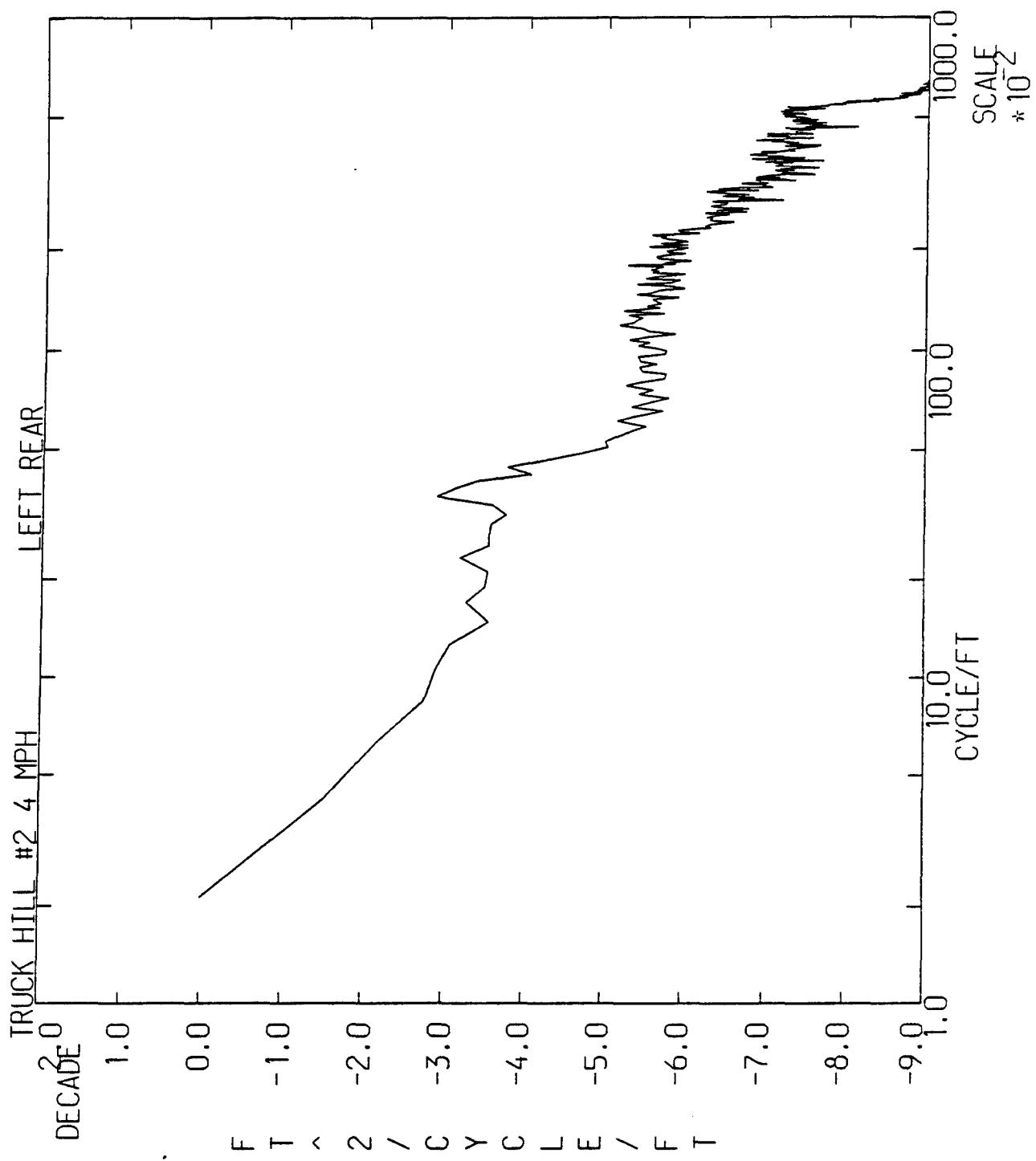
DFMV Speed MPH	Expected Wavelength Resolution*	Actual Wavelength Resolution**
2	60	15
4	120	30
6	180	45
8	240	60
10	300	75

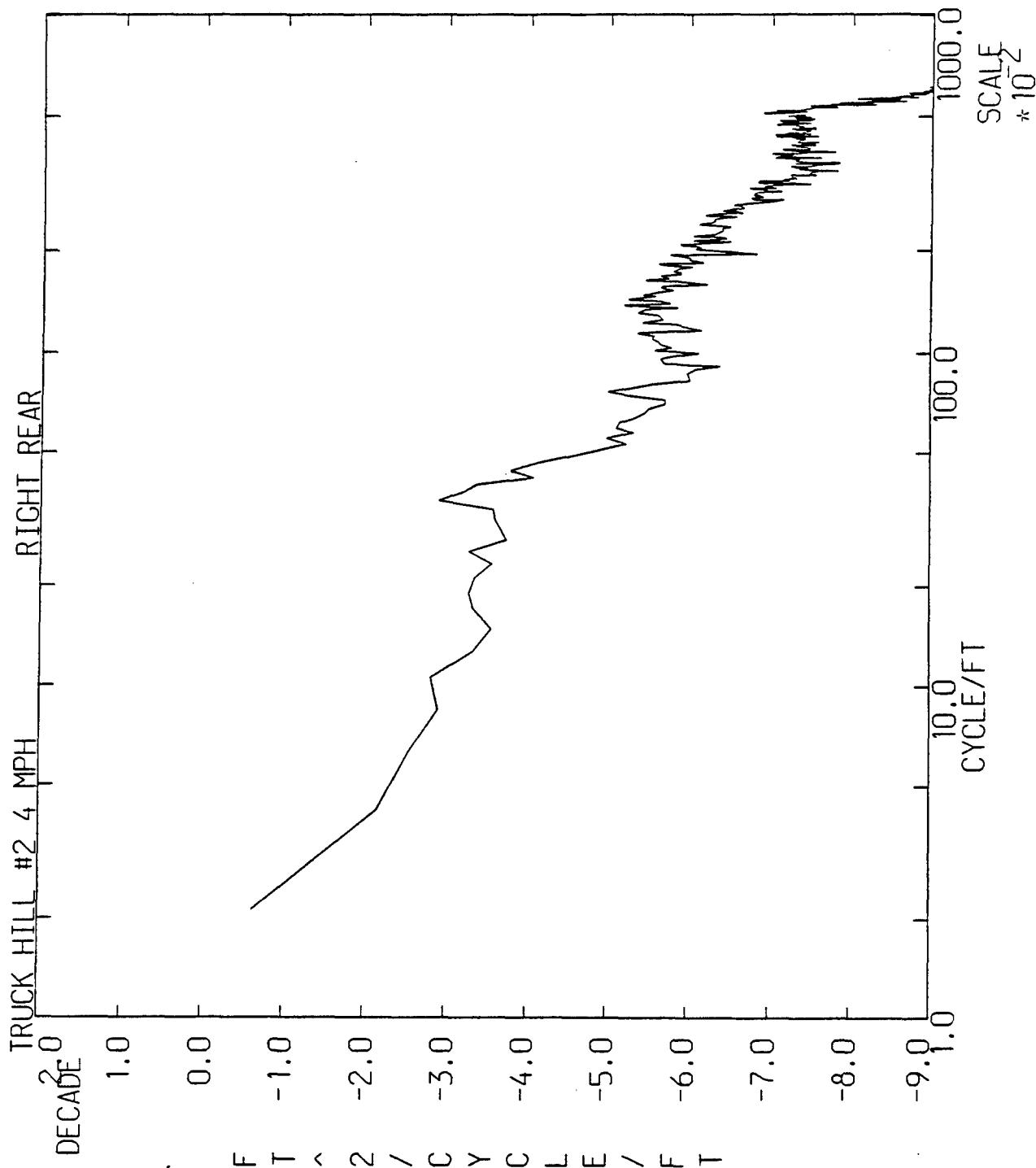
* Based on the advertised low-end frequency range for the accelerometer used

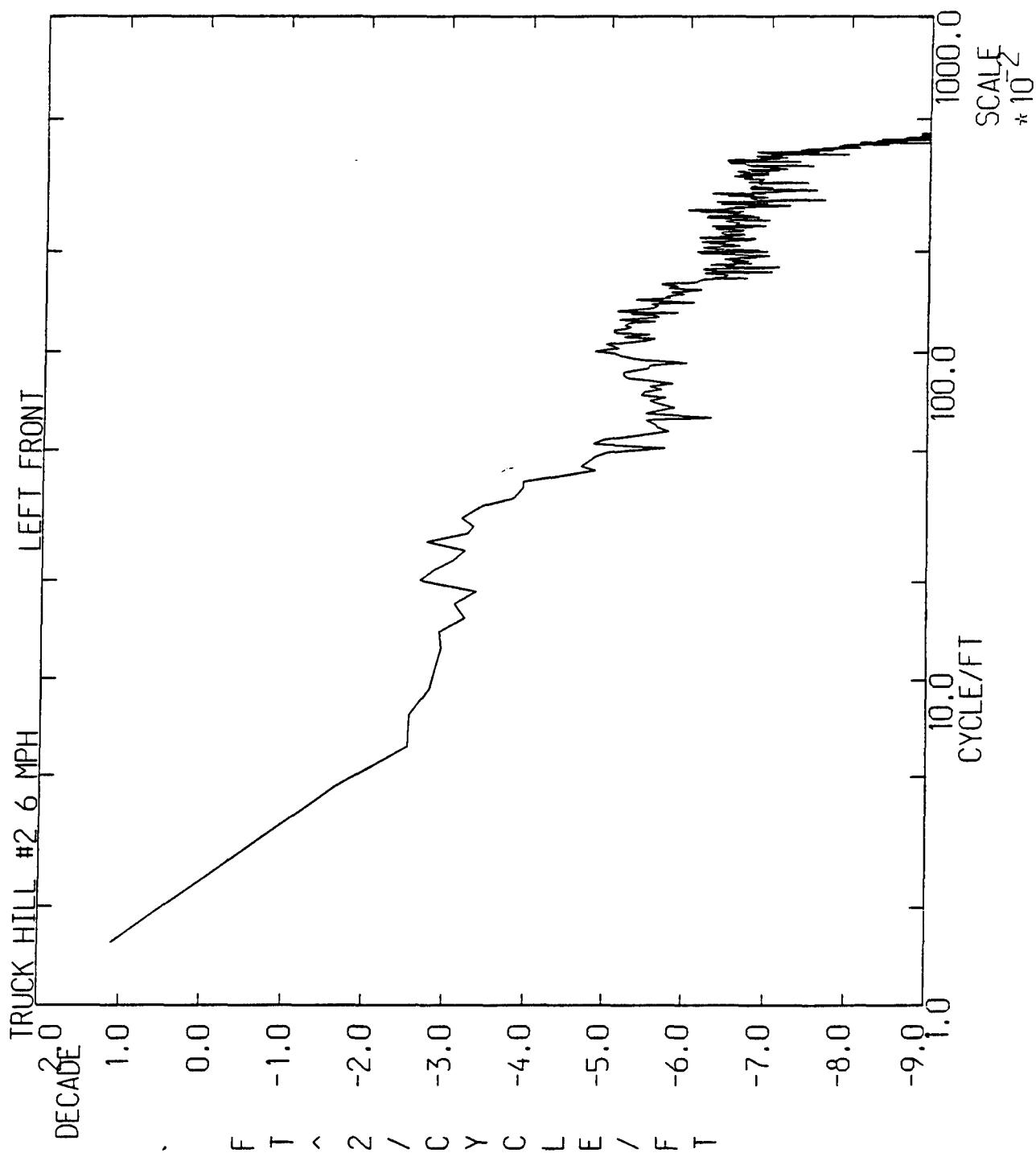
** Based on actual low-end frequency range for the accelerometer used

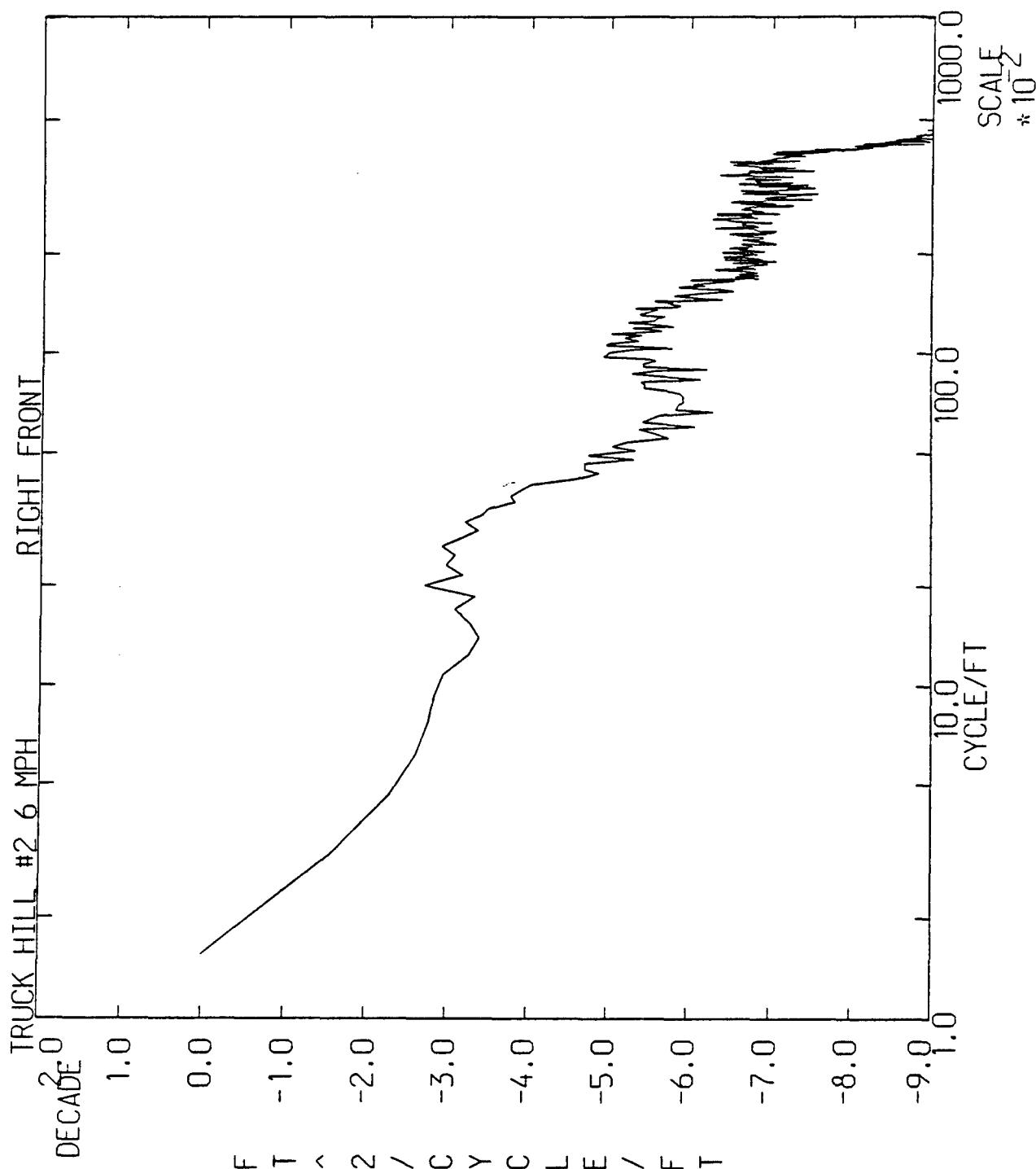


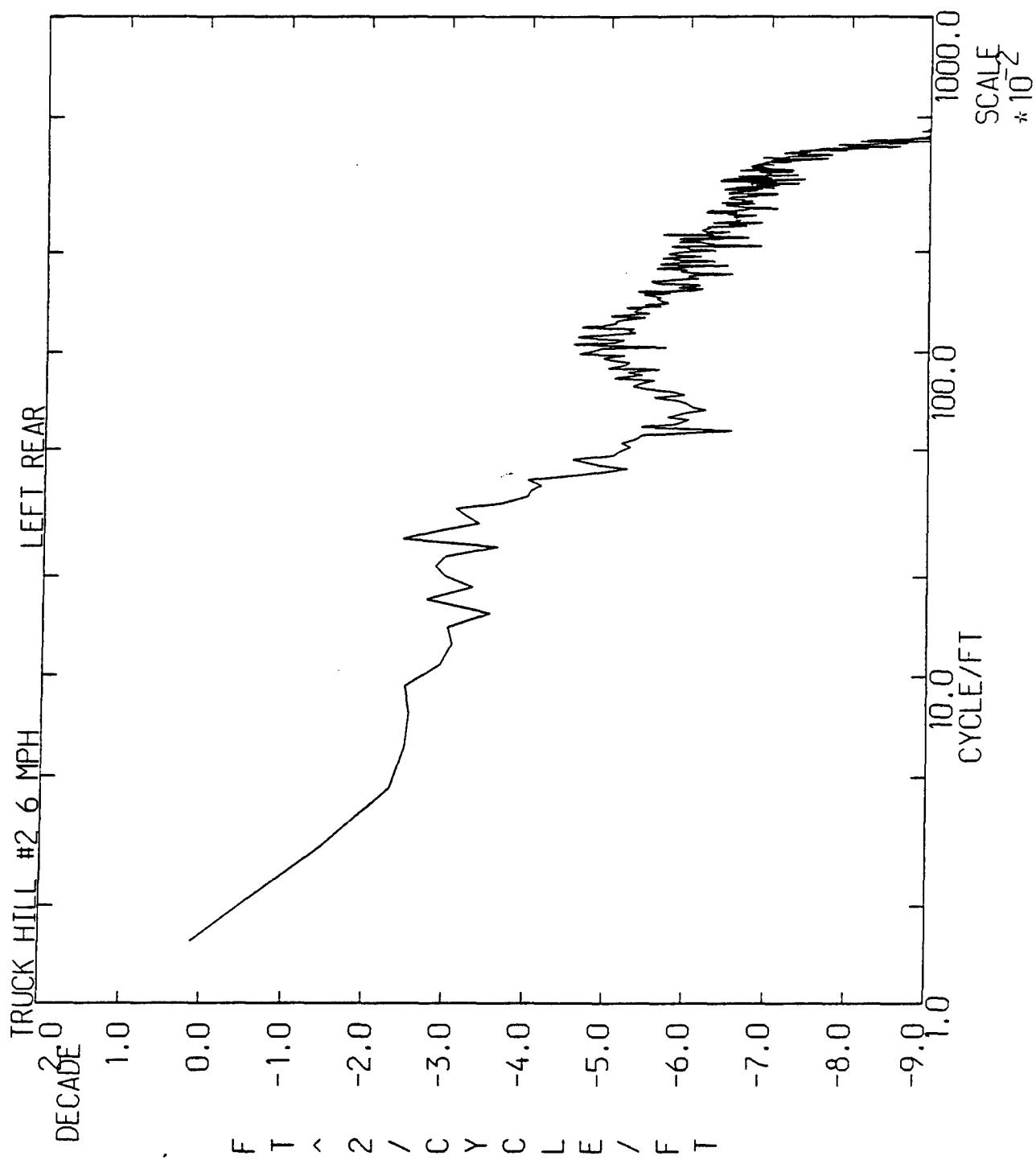


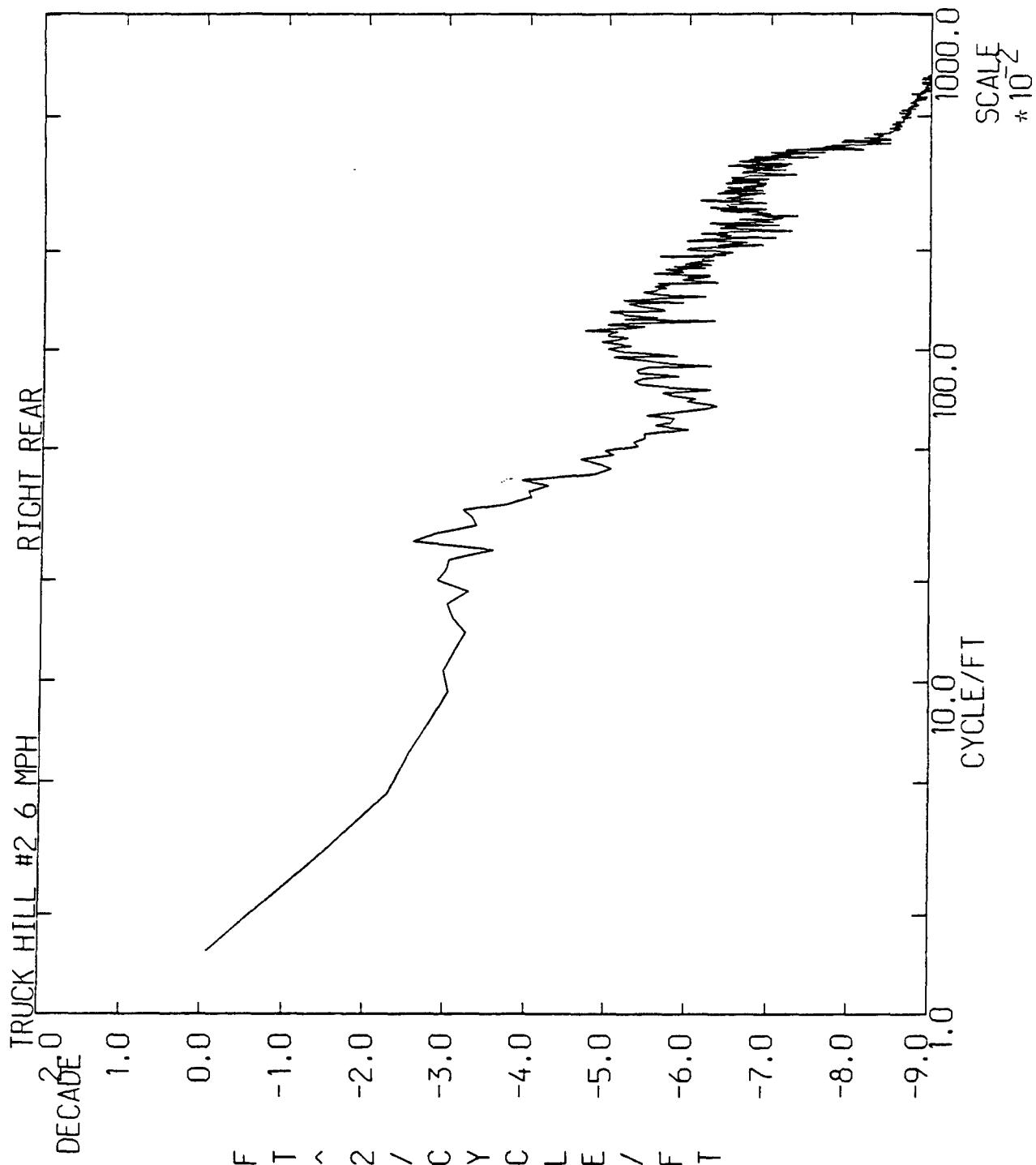


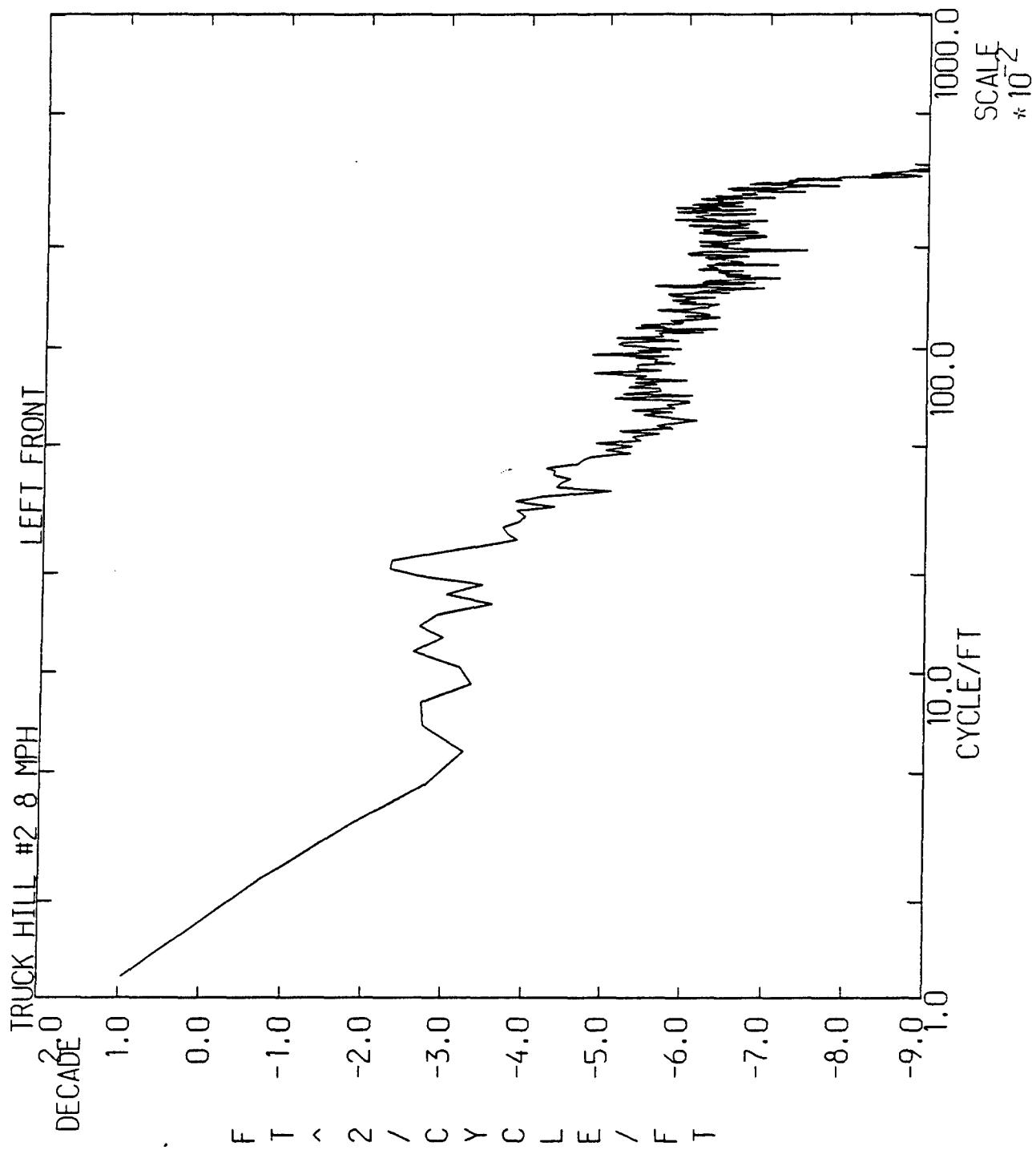


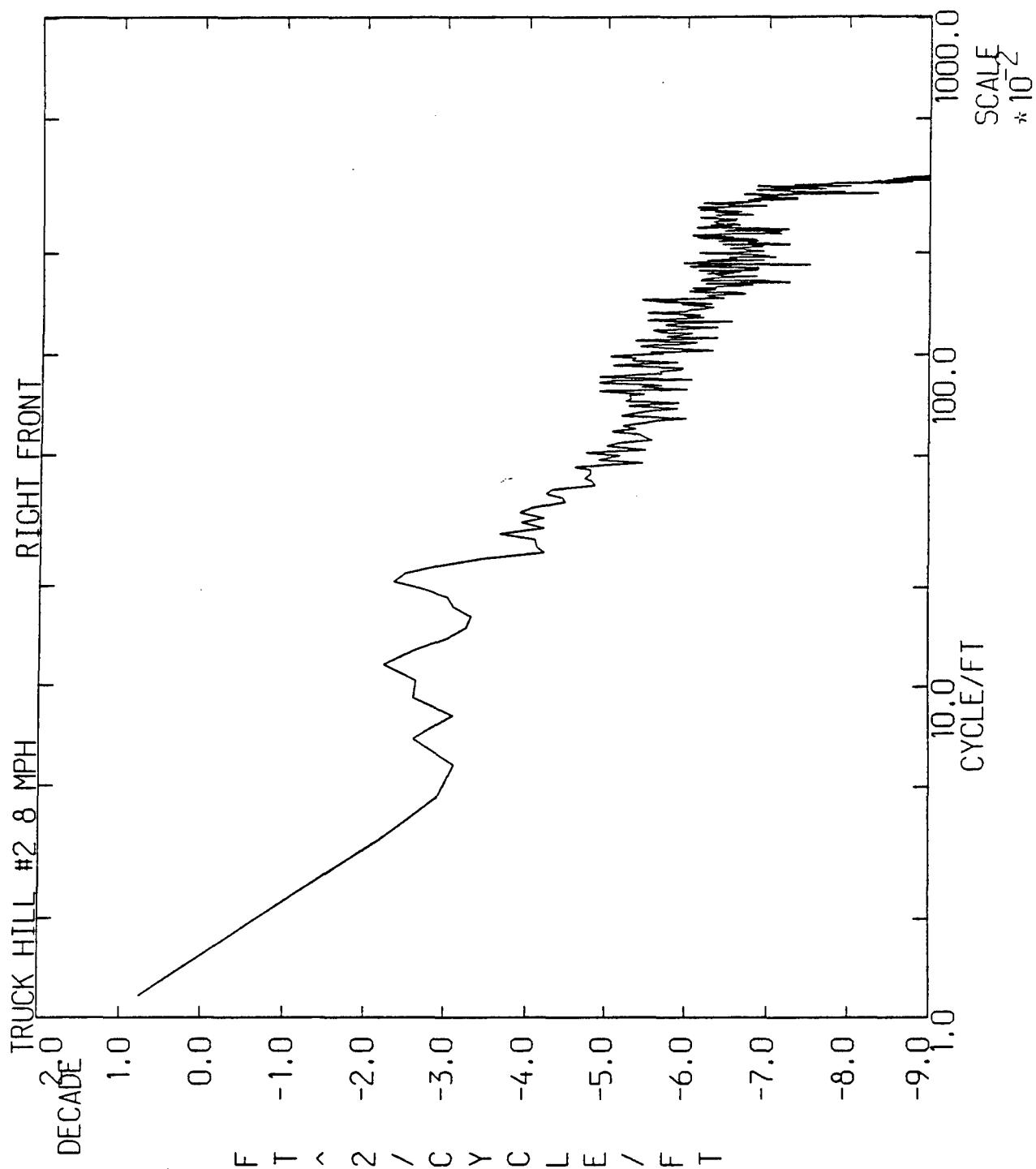


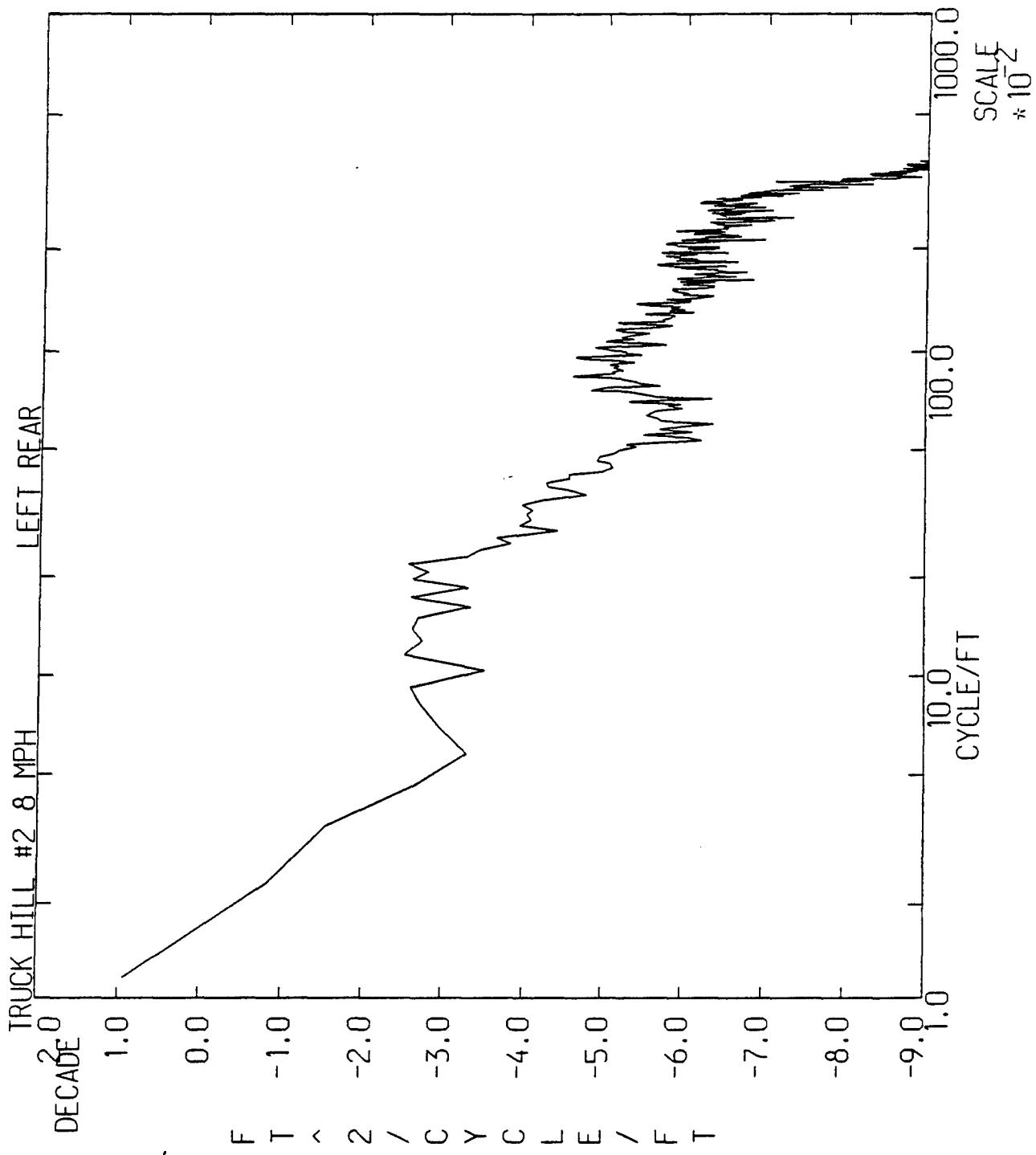




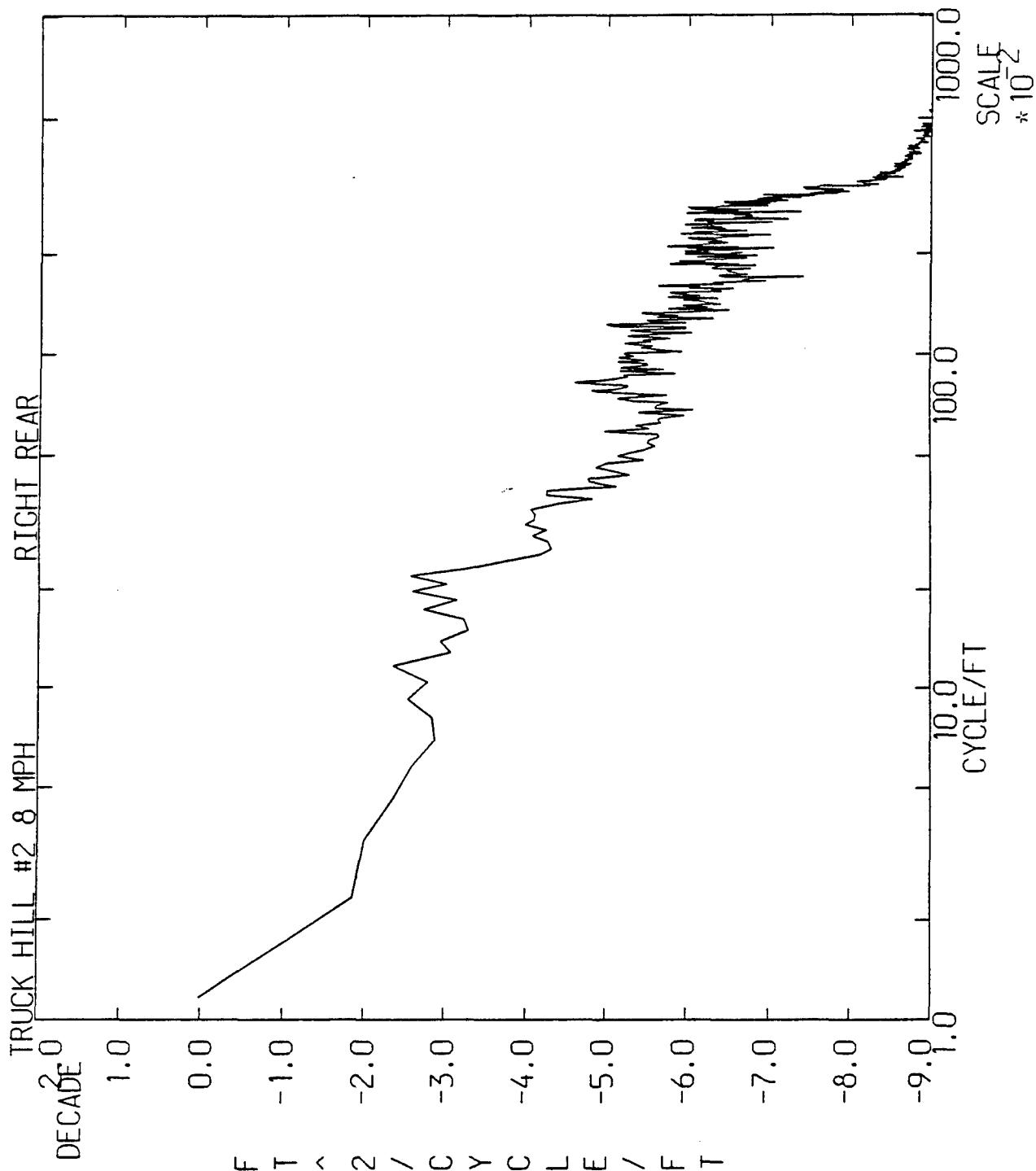


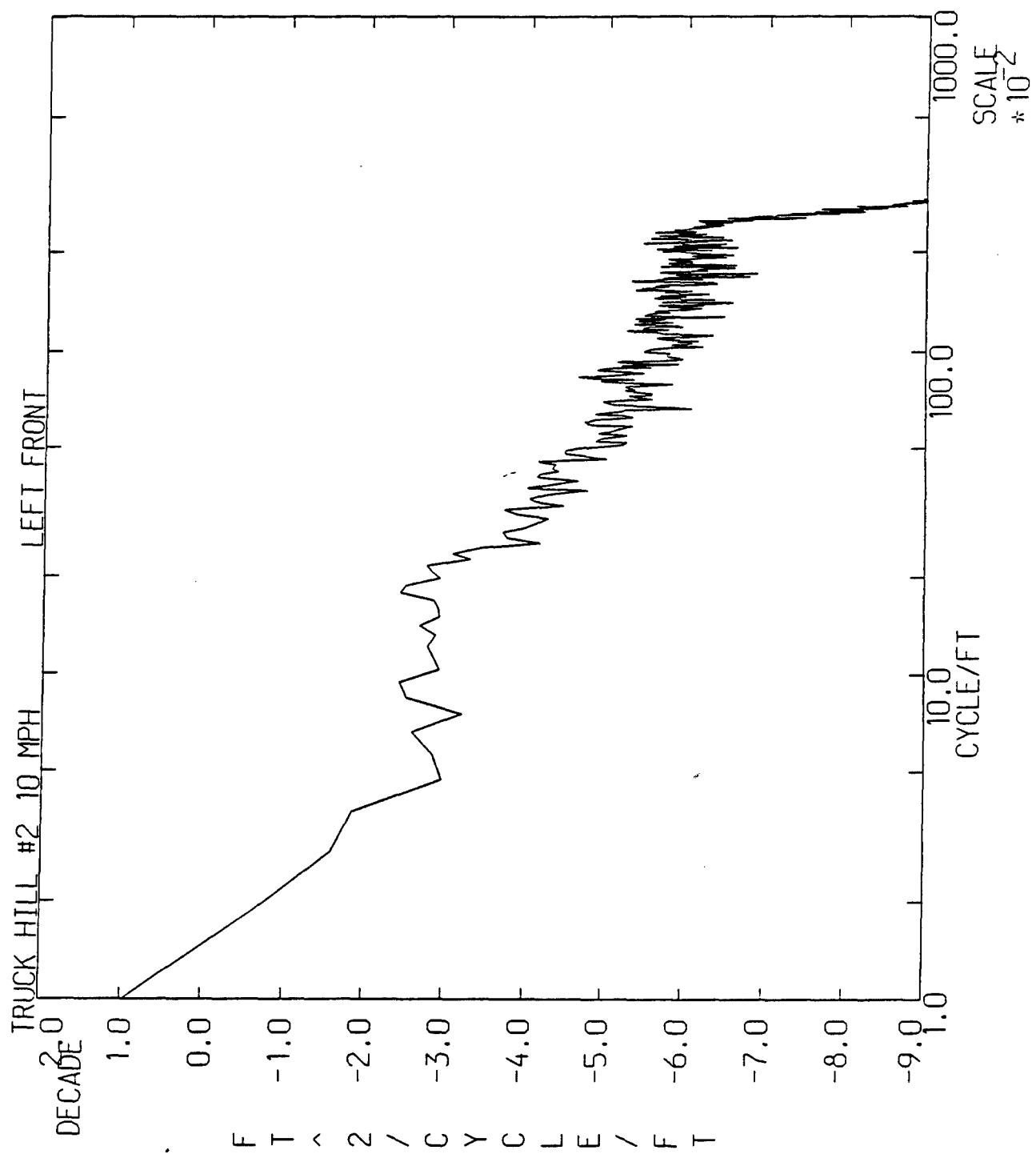


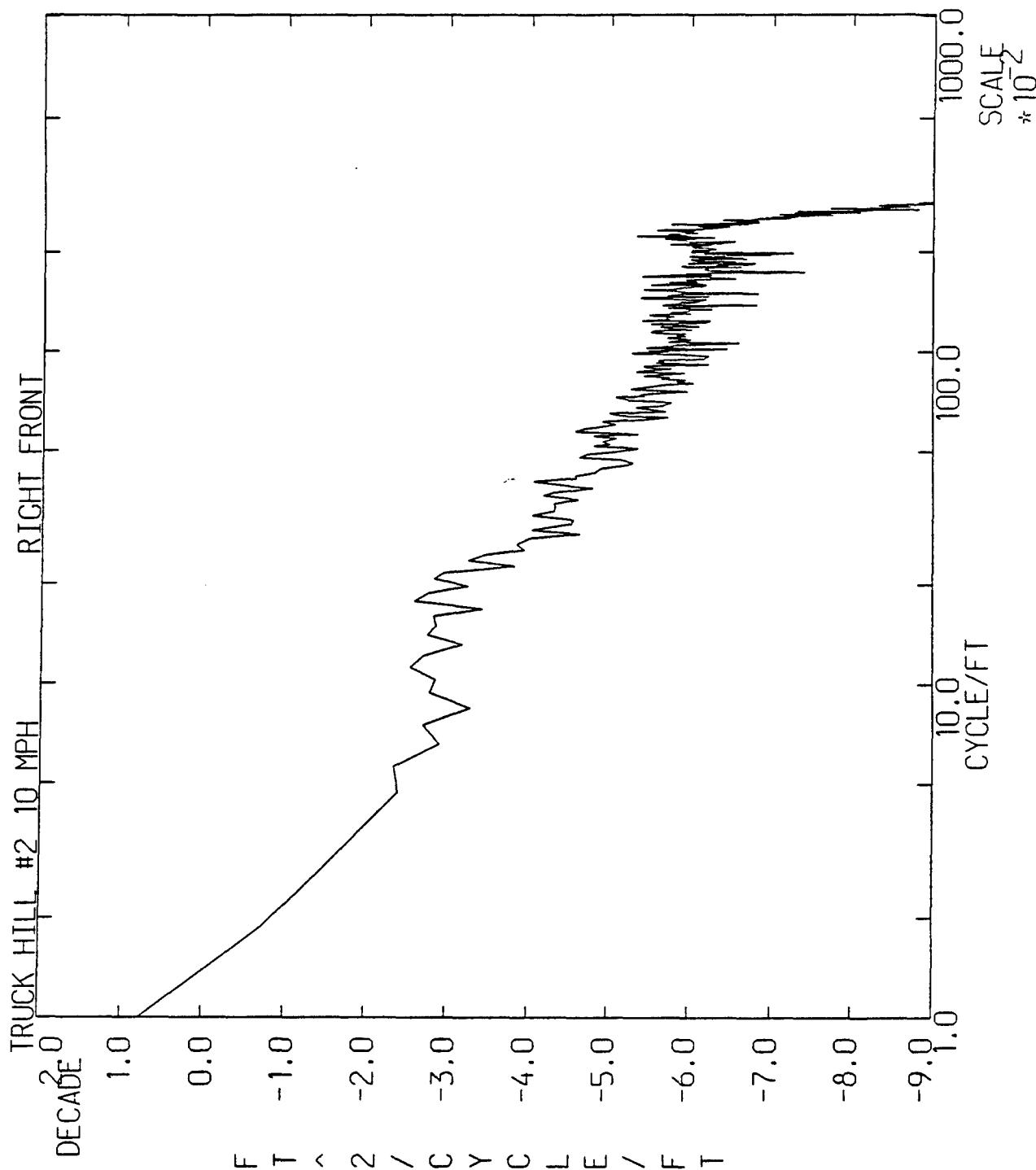


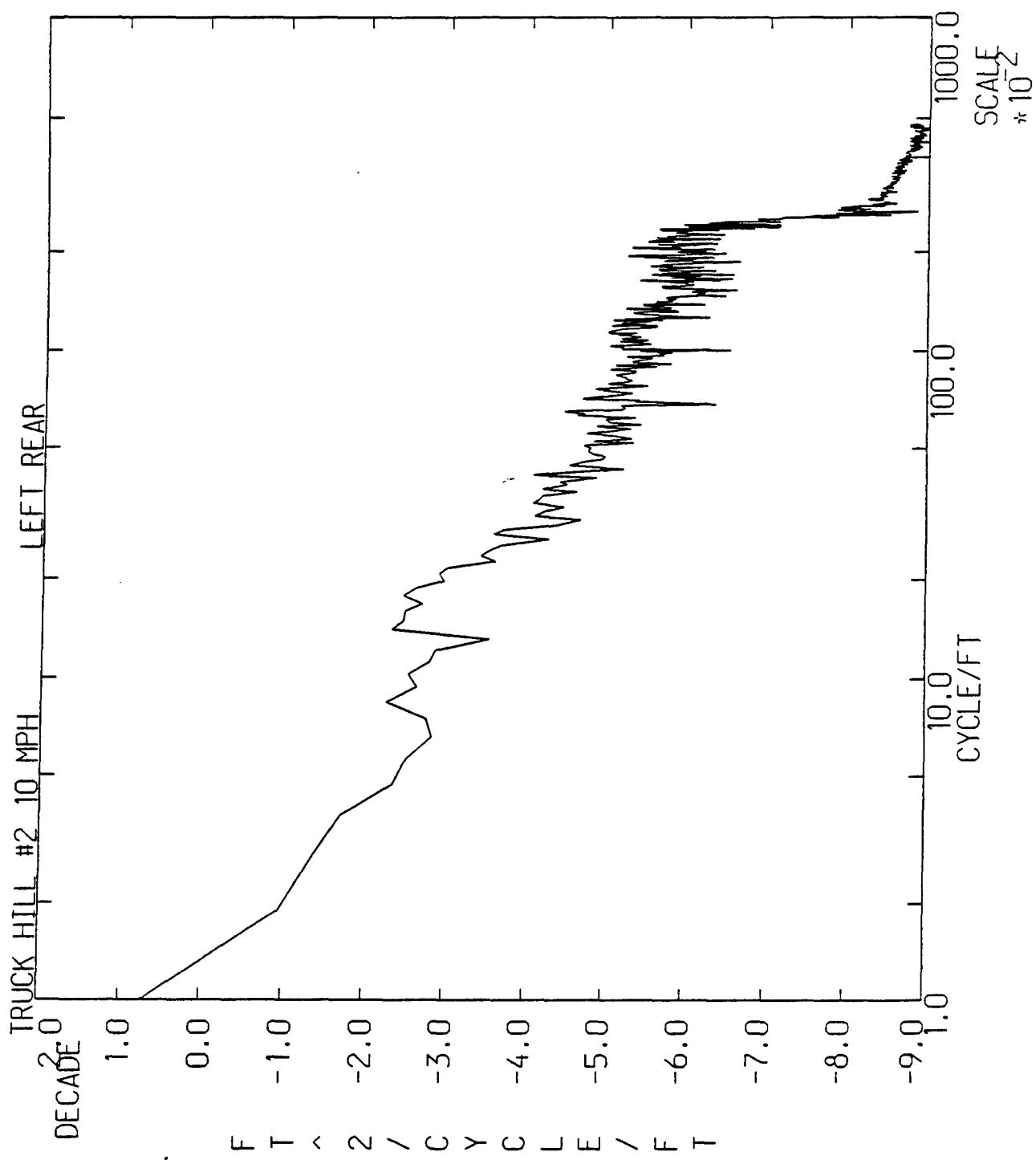


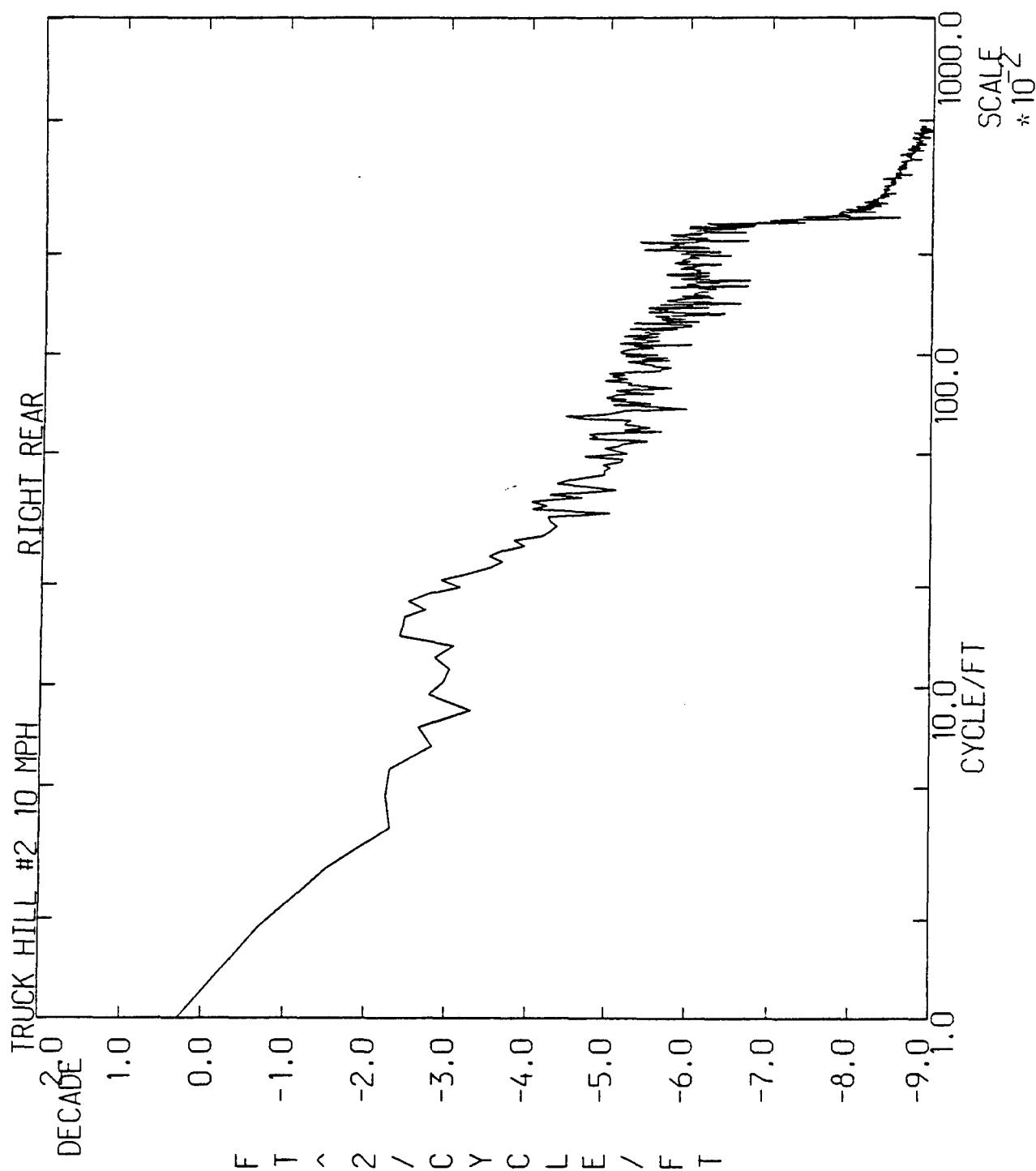
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TRUCK HILL #3

WAVE-NUMBER SPECTRA

2, 4, 6, 8 and 10 MPH

Four (4) curves per speed, one for each DFMV tire, as follows

LEFT FRONT
RIGHT FRONT
LEFT REAR
RIGHT REAR

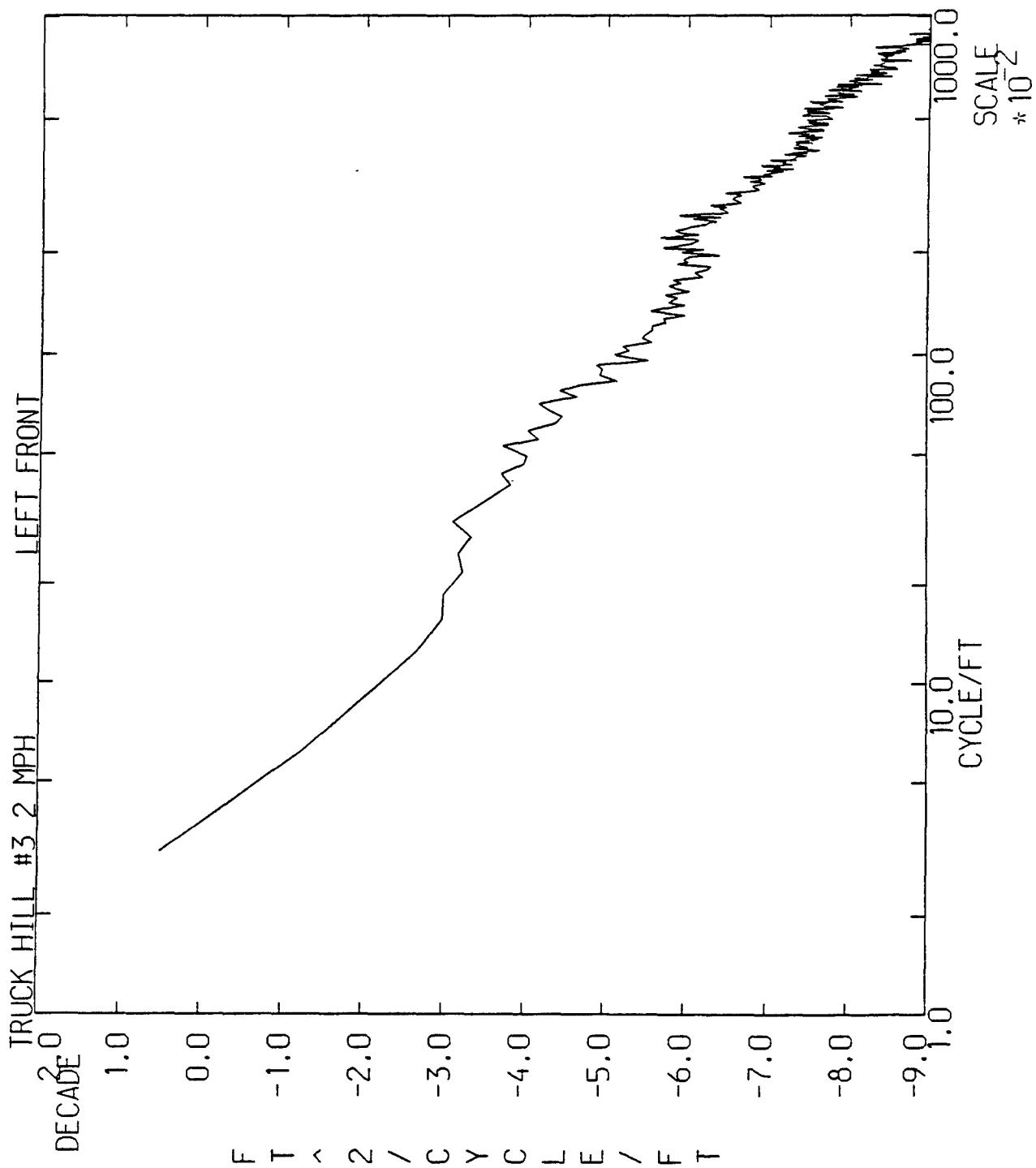
Volume II contains the data for the different DFMV speeds over each YPG course. The data was previously submitted to TACOM in an interim data report, however, the data was not reprocessed with the signal processing considerations discussed in the Volume I report (e.g., in this data, much of the spectral resolution was below the footprint). The wave-number cut-off at the low end of the spectra was limited by the frequency range of the accelerometer, as discussed in the report and shown in the table below. The wave-number cut-off at the high end of the spectrum was limited by the footprint length of the DFMV tire, which was $\approx 1.2 \text{ ft}^{-1}$. These cut-offs were verified through the DFMV front-to-rear coherence plots. Therefore, when comparing plots between different speeds, do not compare the data past these limits. As discussed in the report, the faster speed runs produced the best results at the lower wave numbers.

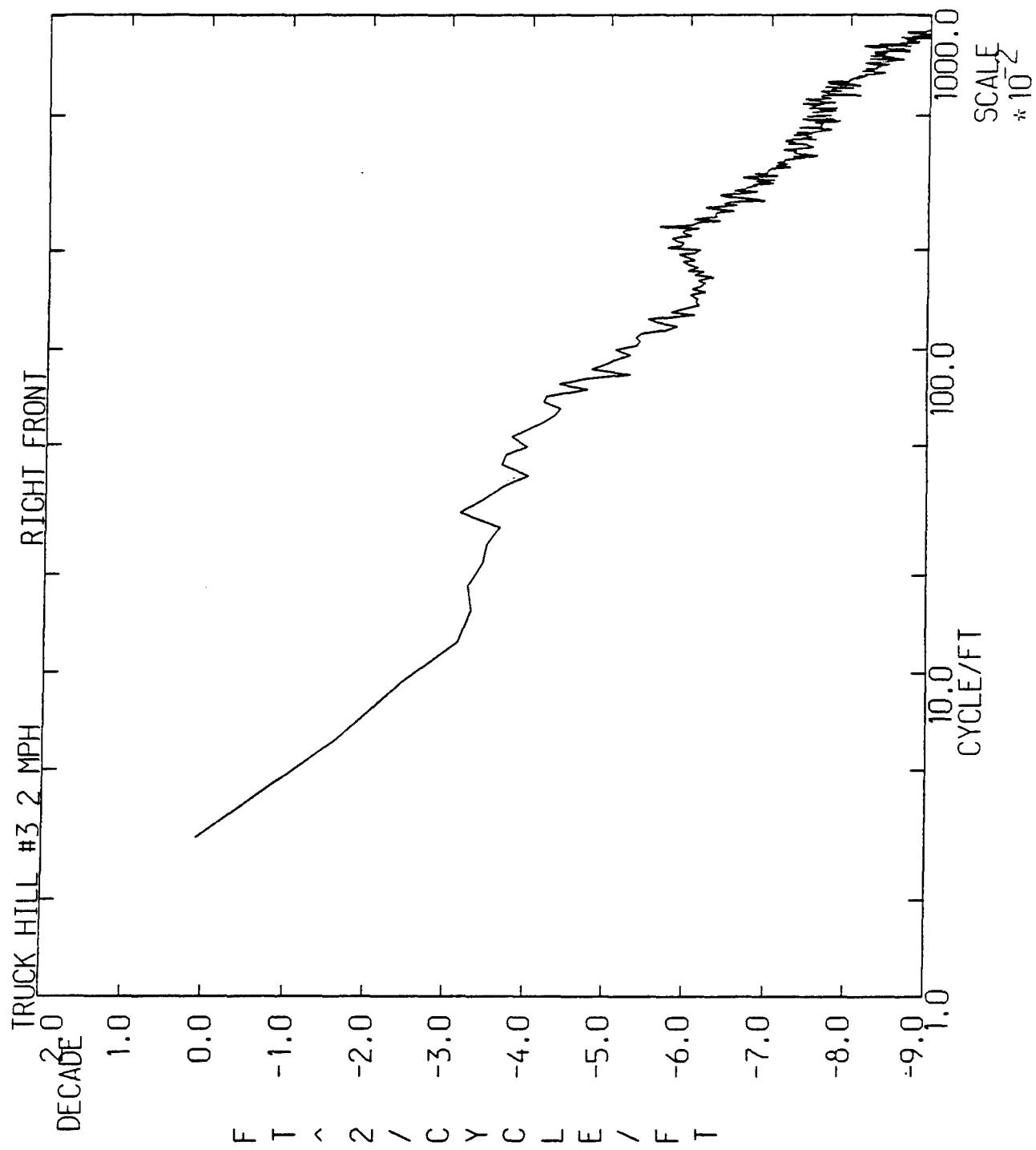
Table 1. DFMV Actual Versus Predicted Wavelength Limits

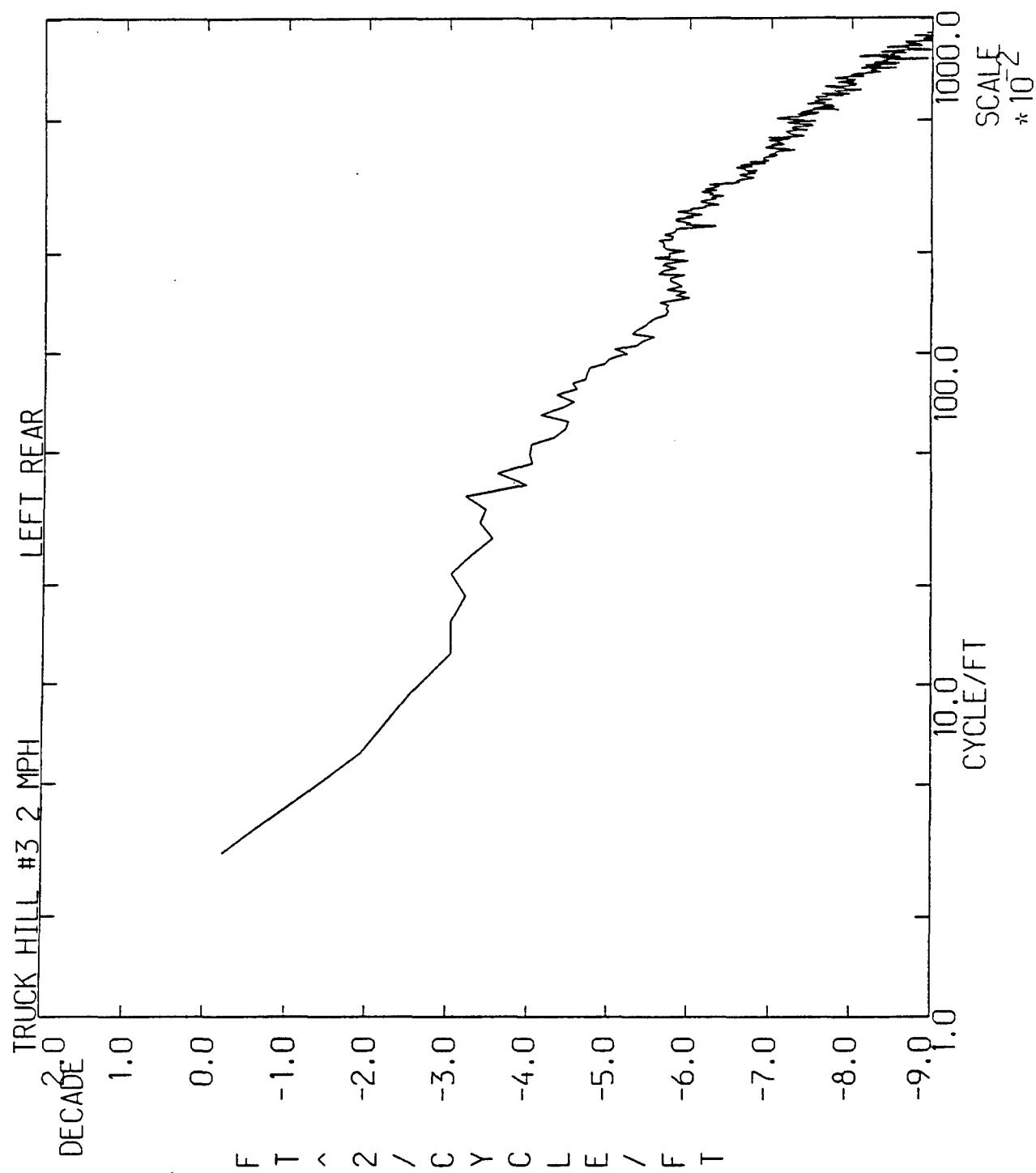
DFMV Speed MPH	Expected Wavelength Resolution*	Actual Wavelength Resolution**
2	60	15
4	120	30
6	180	45
8	240	60
10	300	75

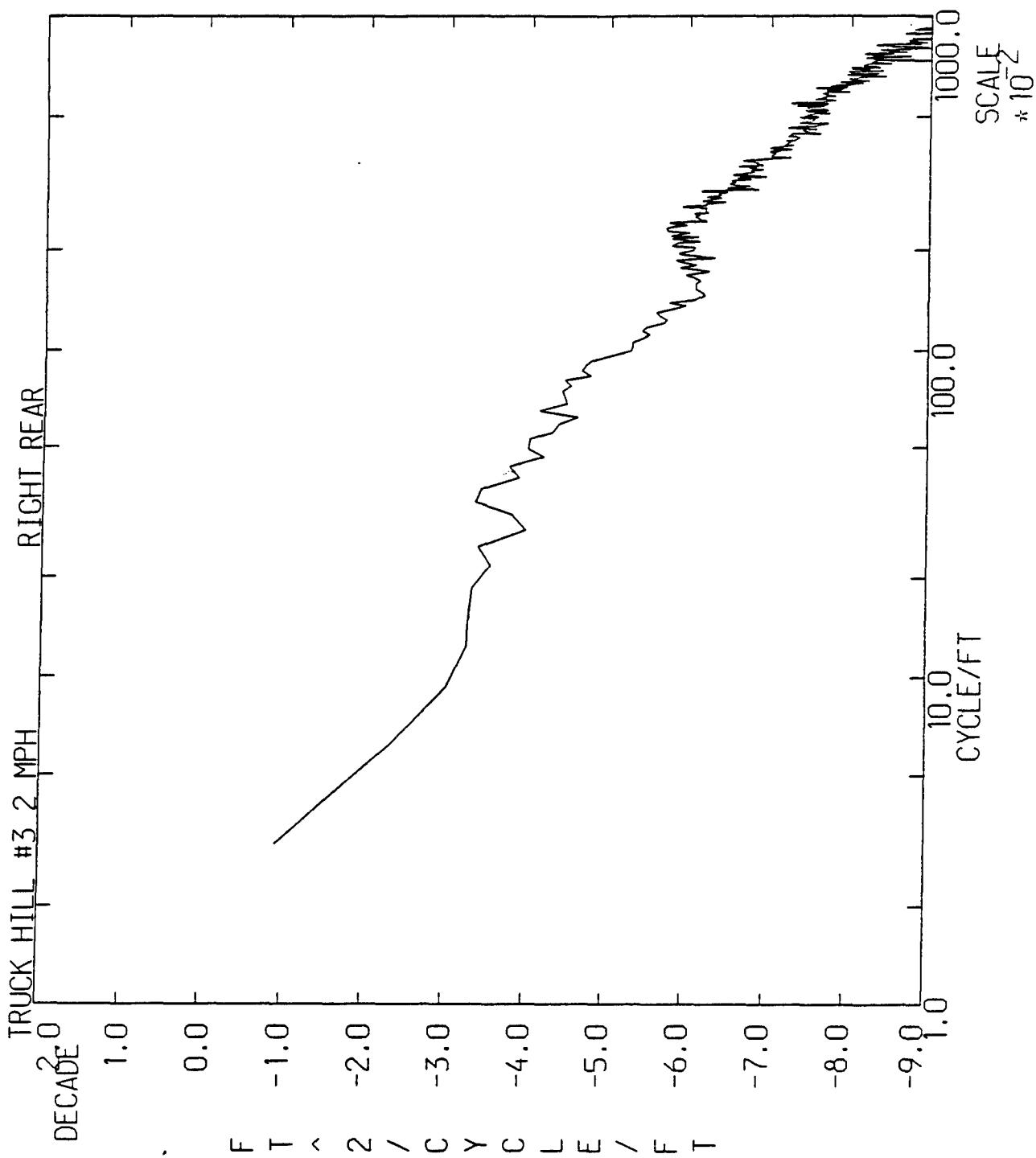
* Based on the advertised low-end frequency range for the accelerometer used

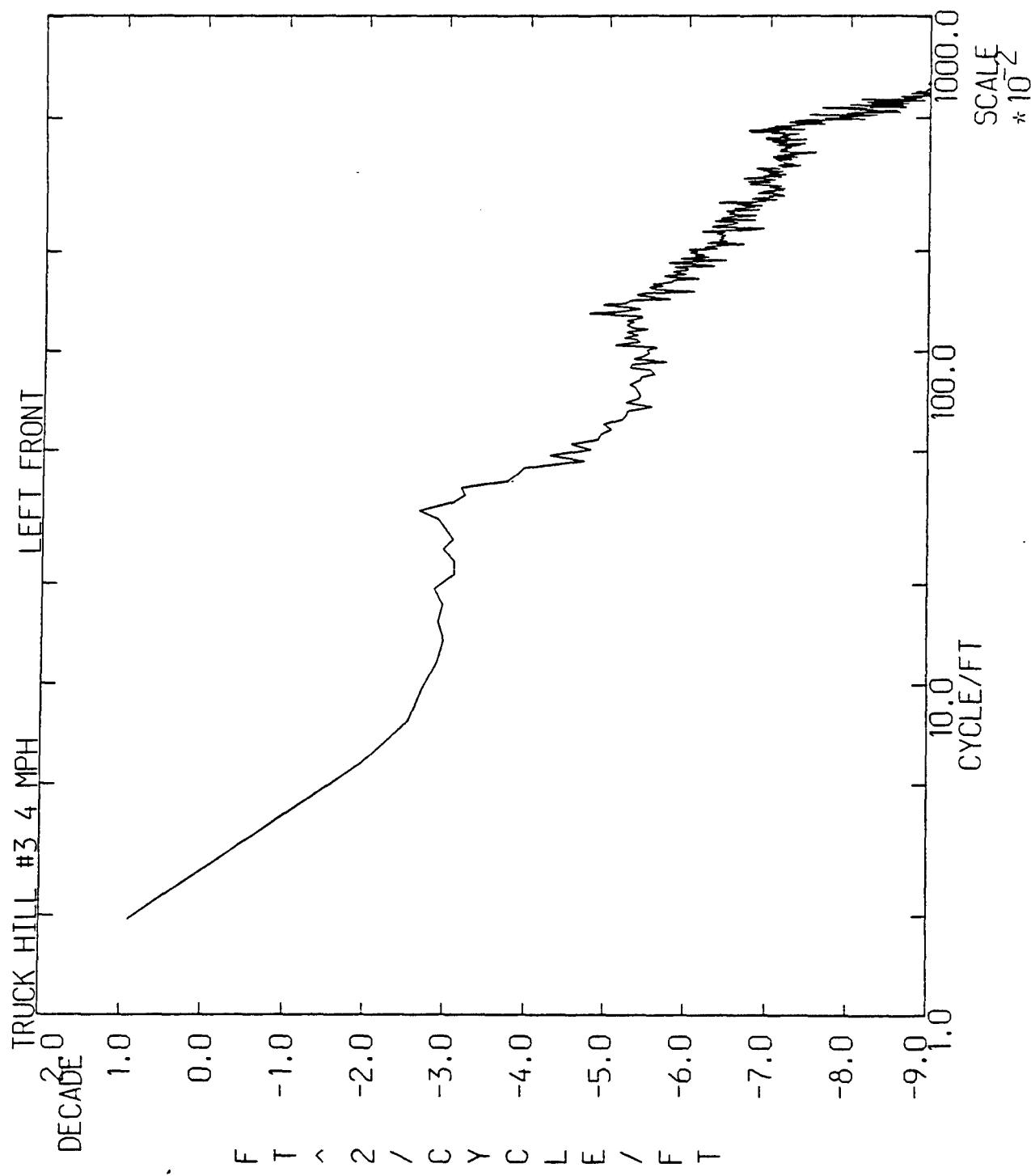
** Based on actual low-end frequency range for the accelerometer used

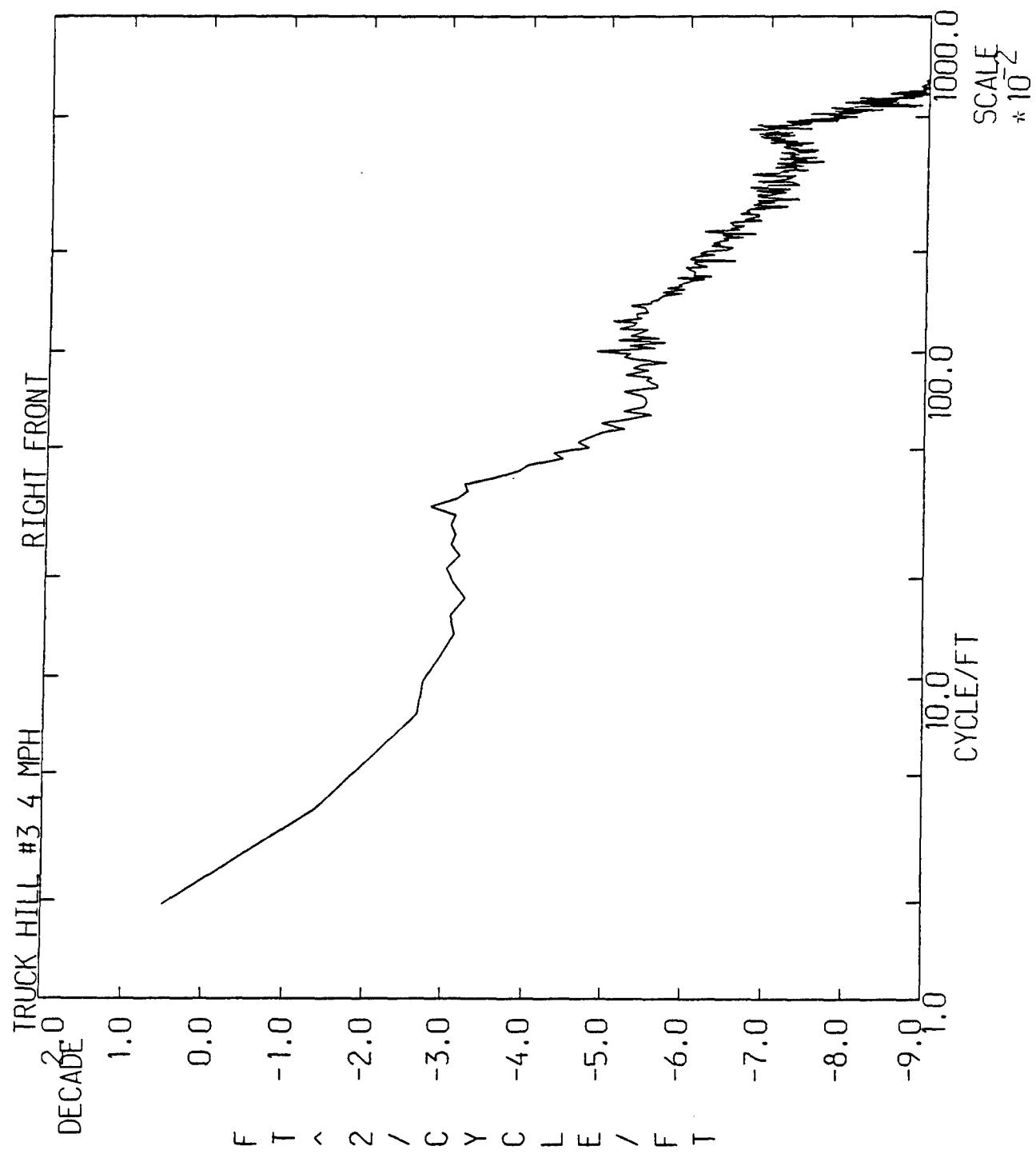


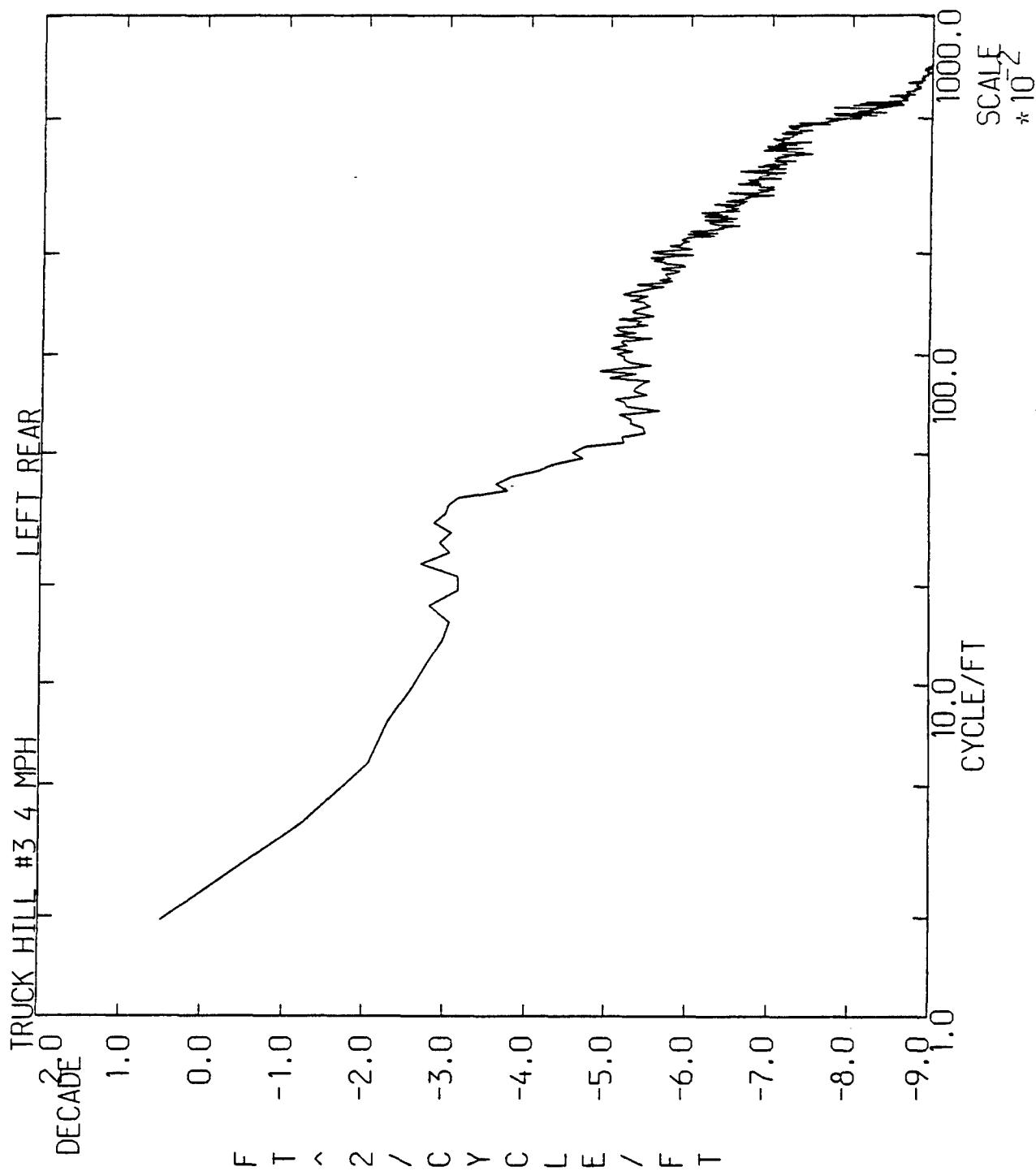


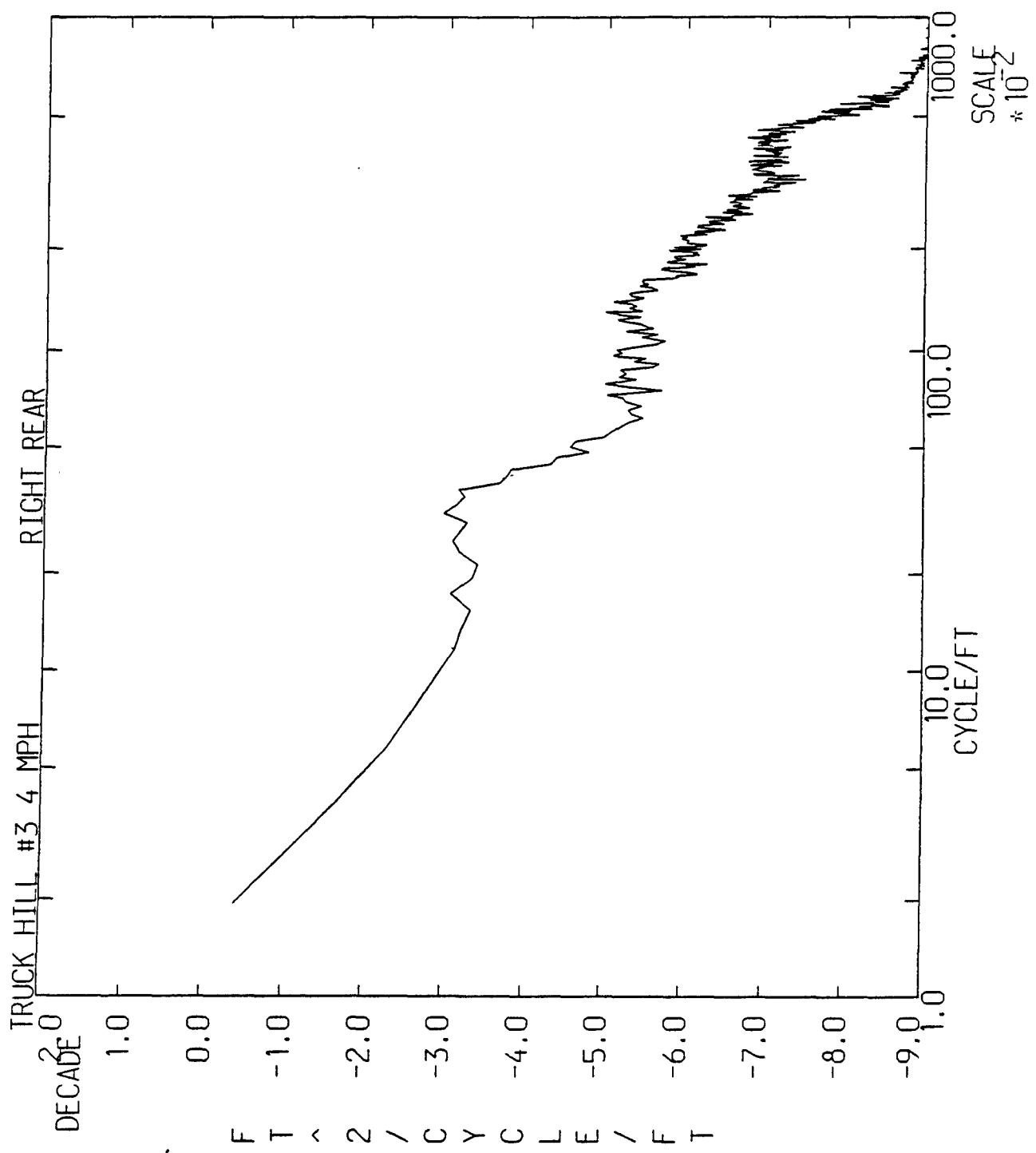


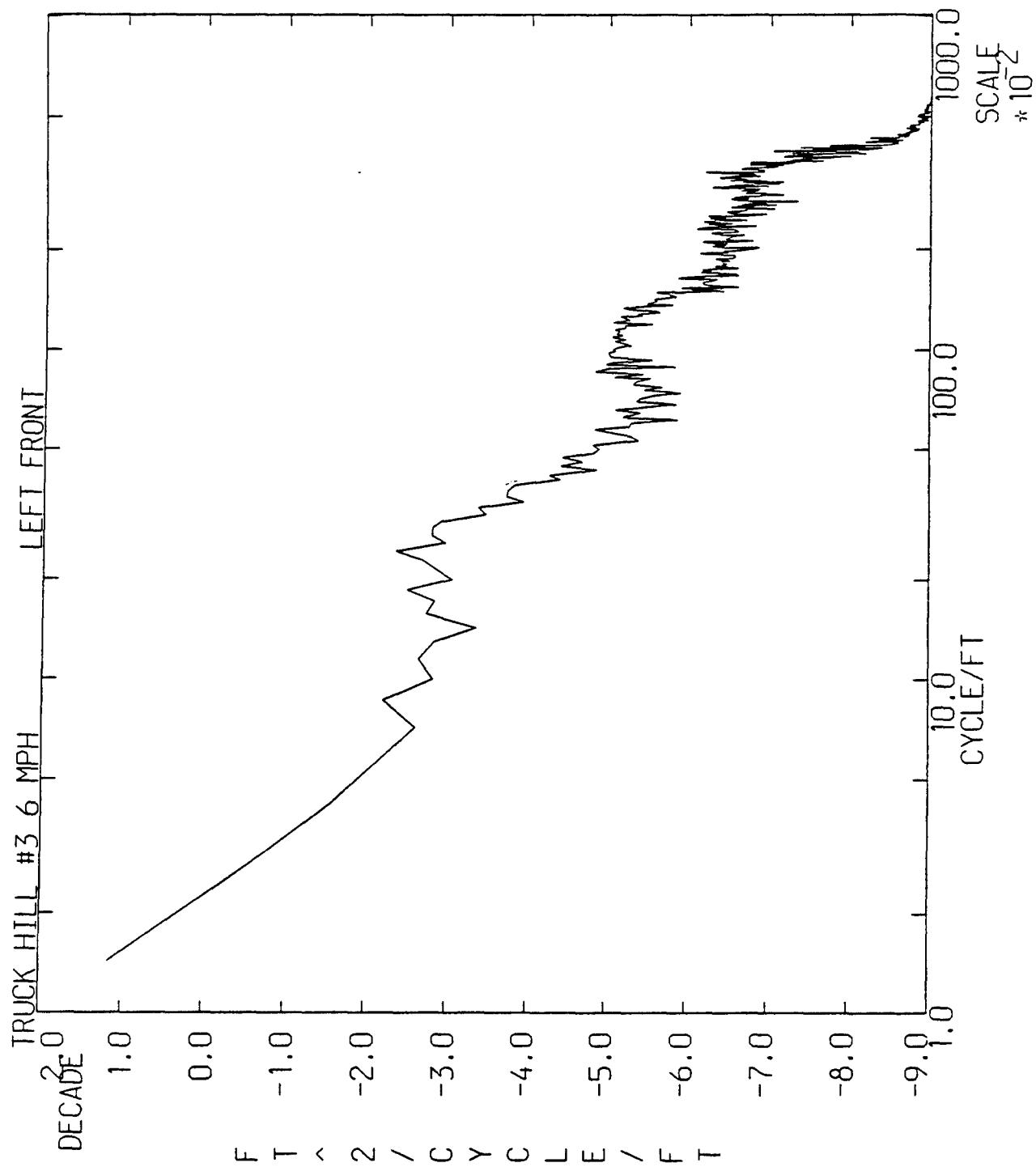


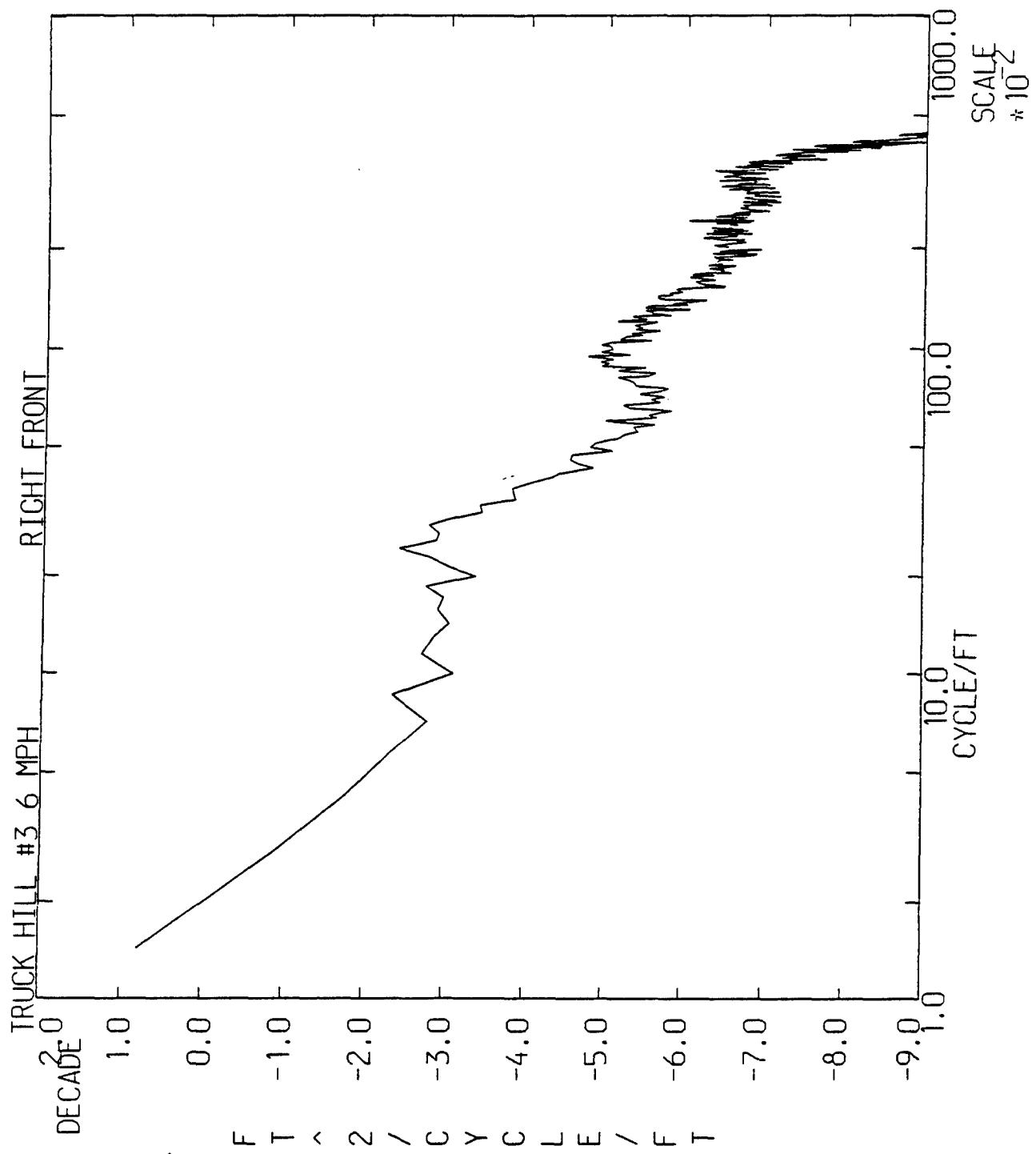


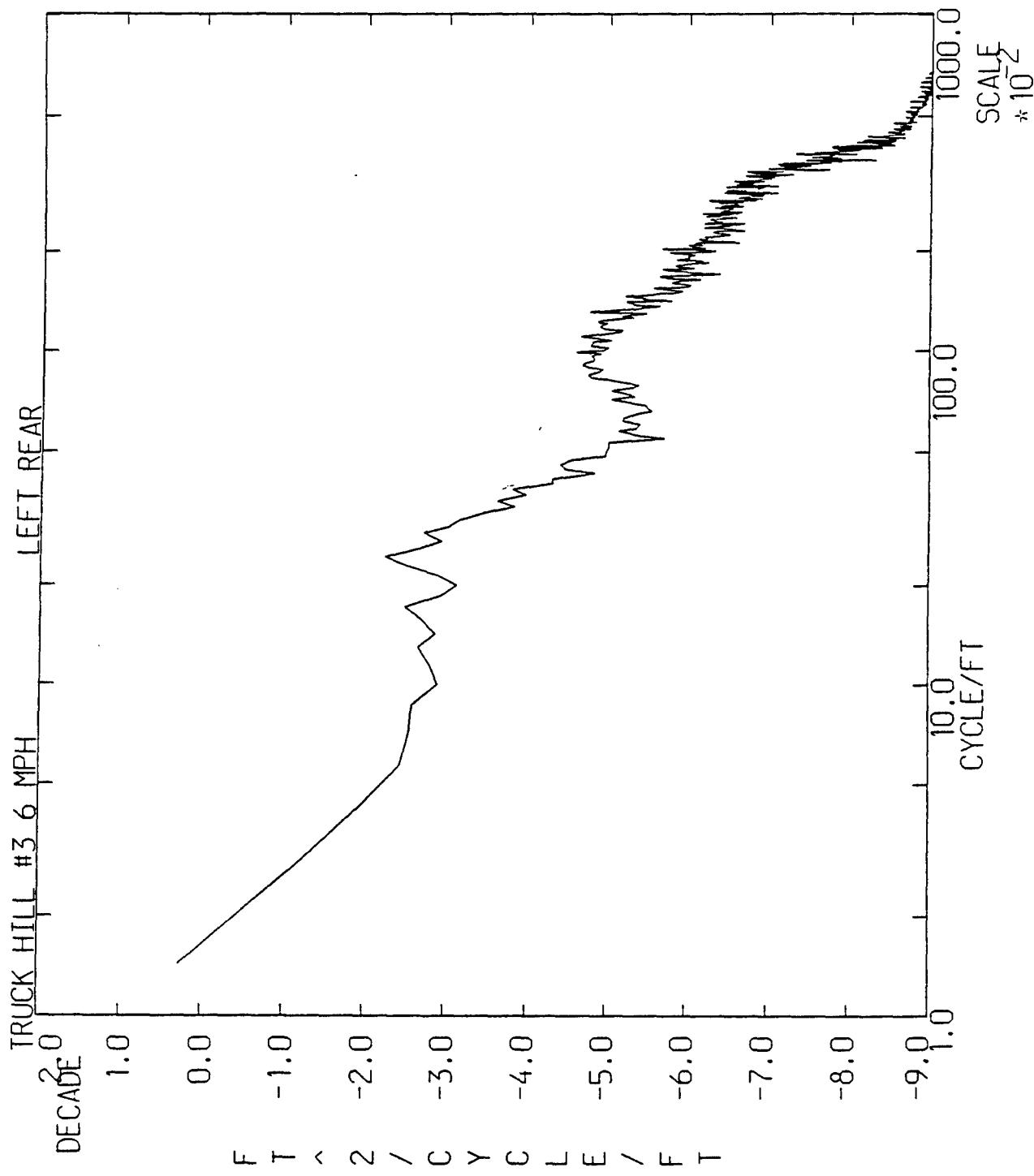


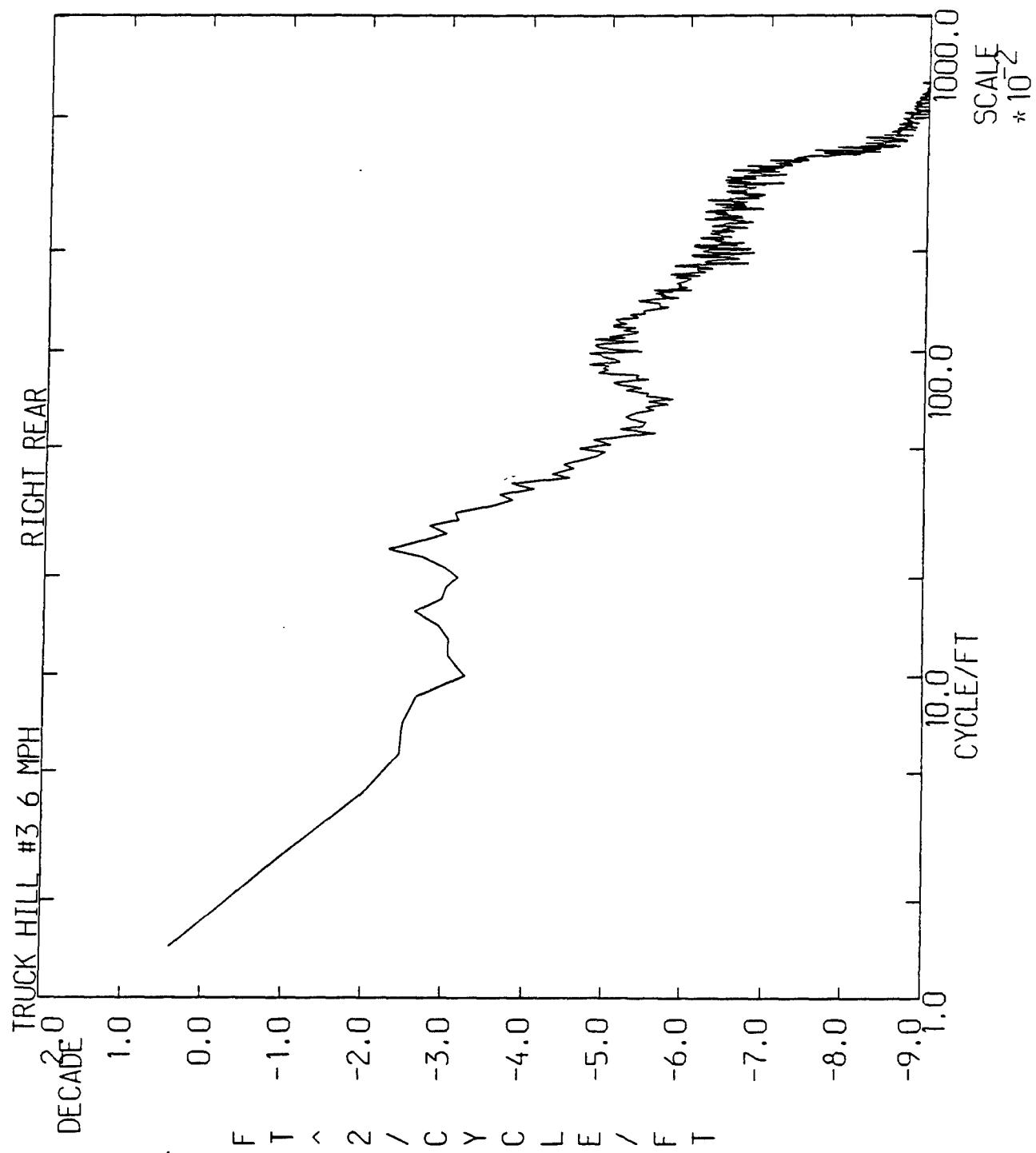


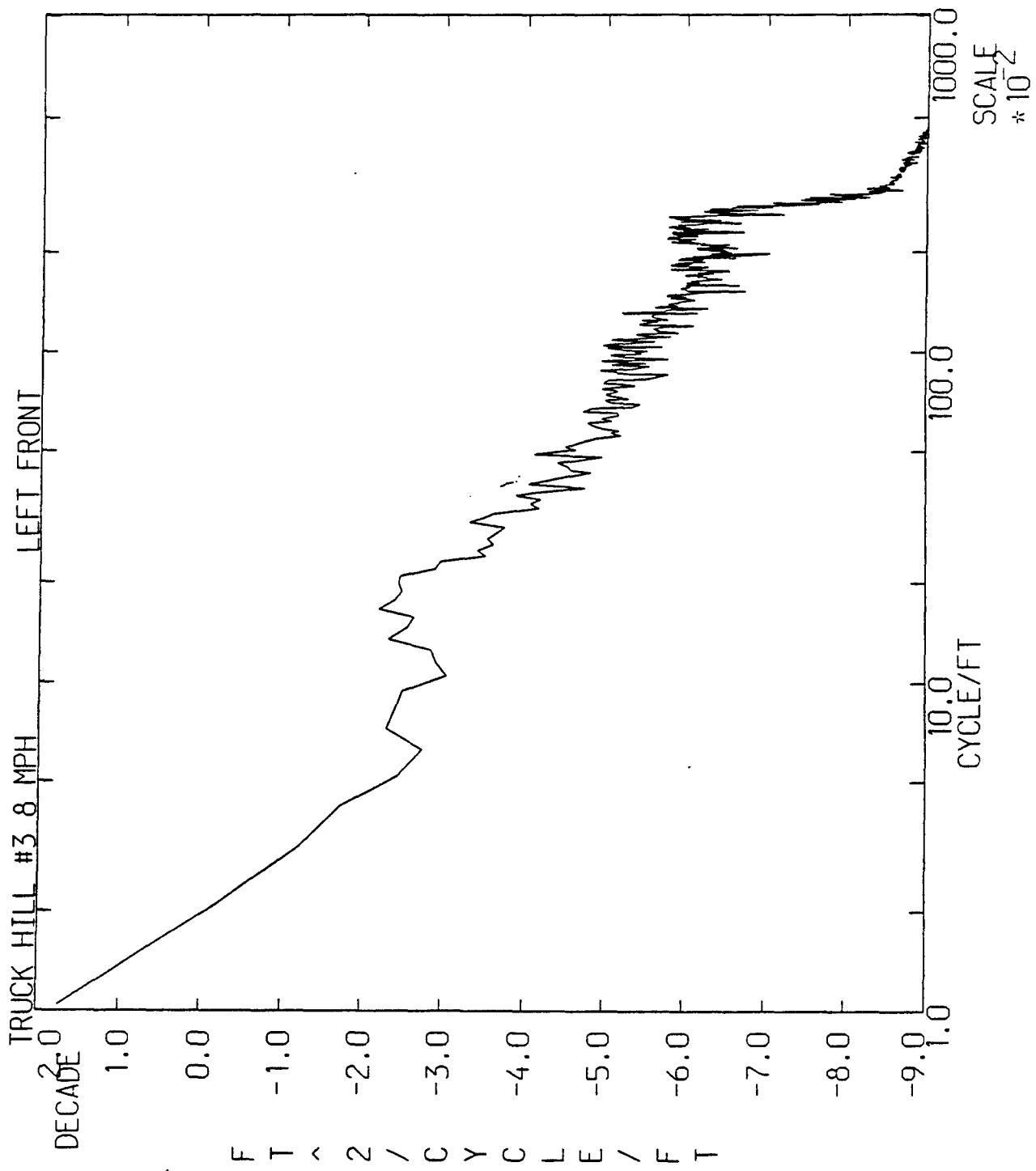




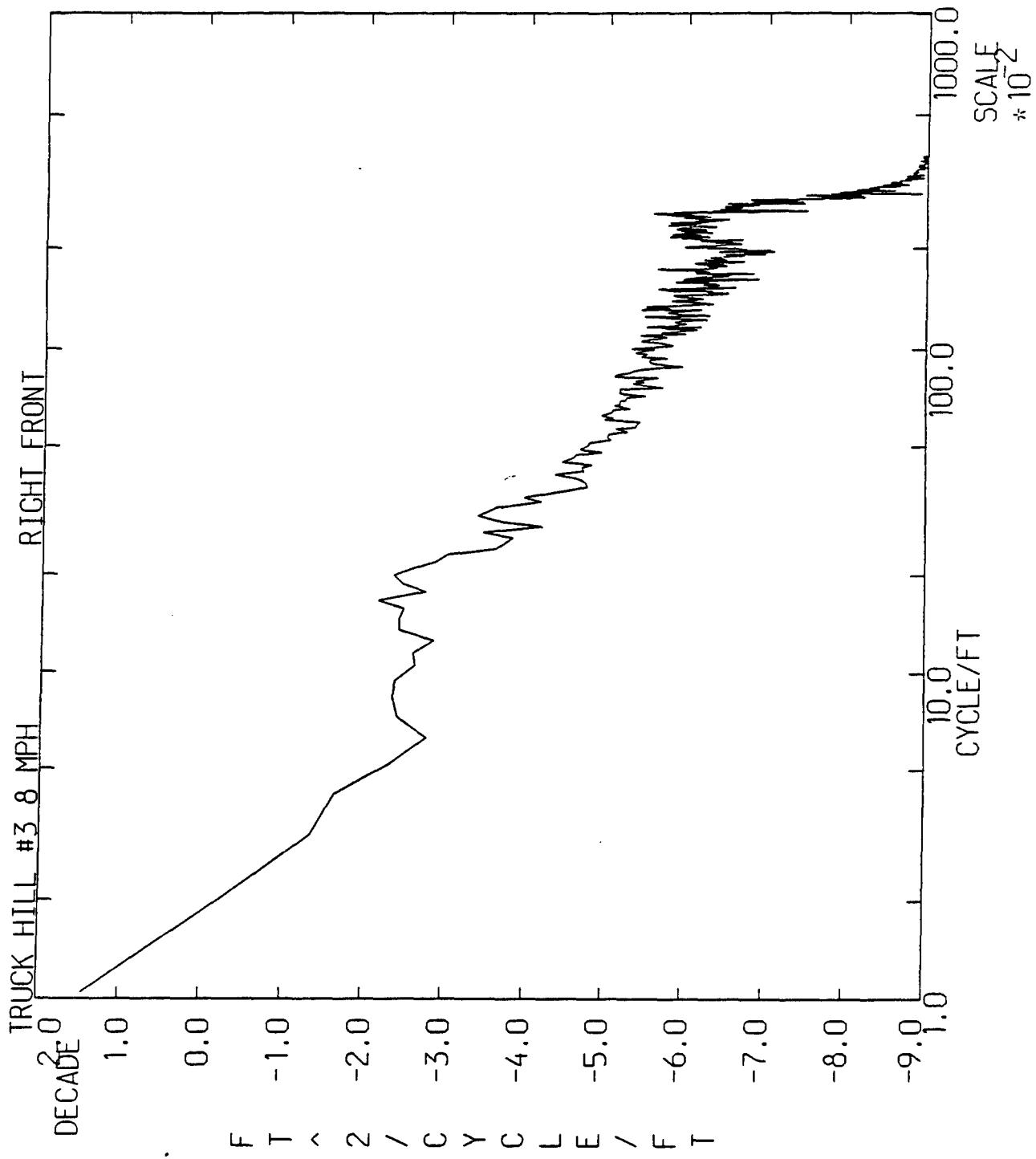


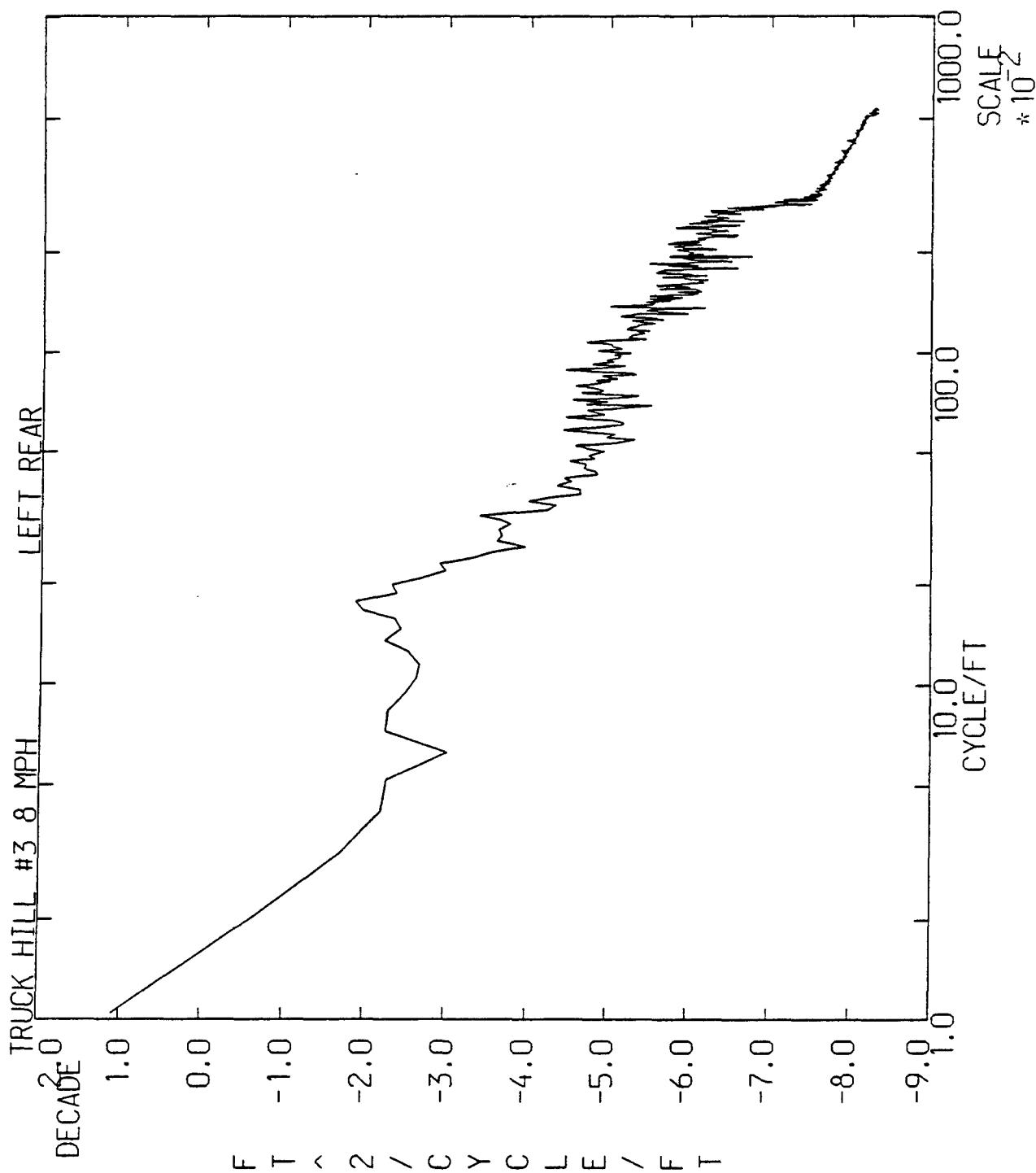


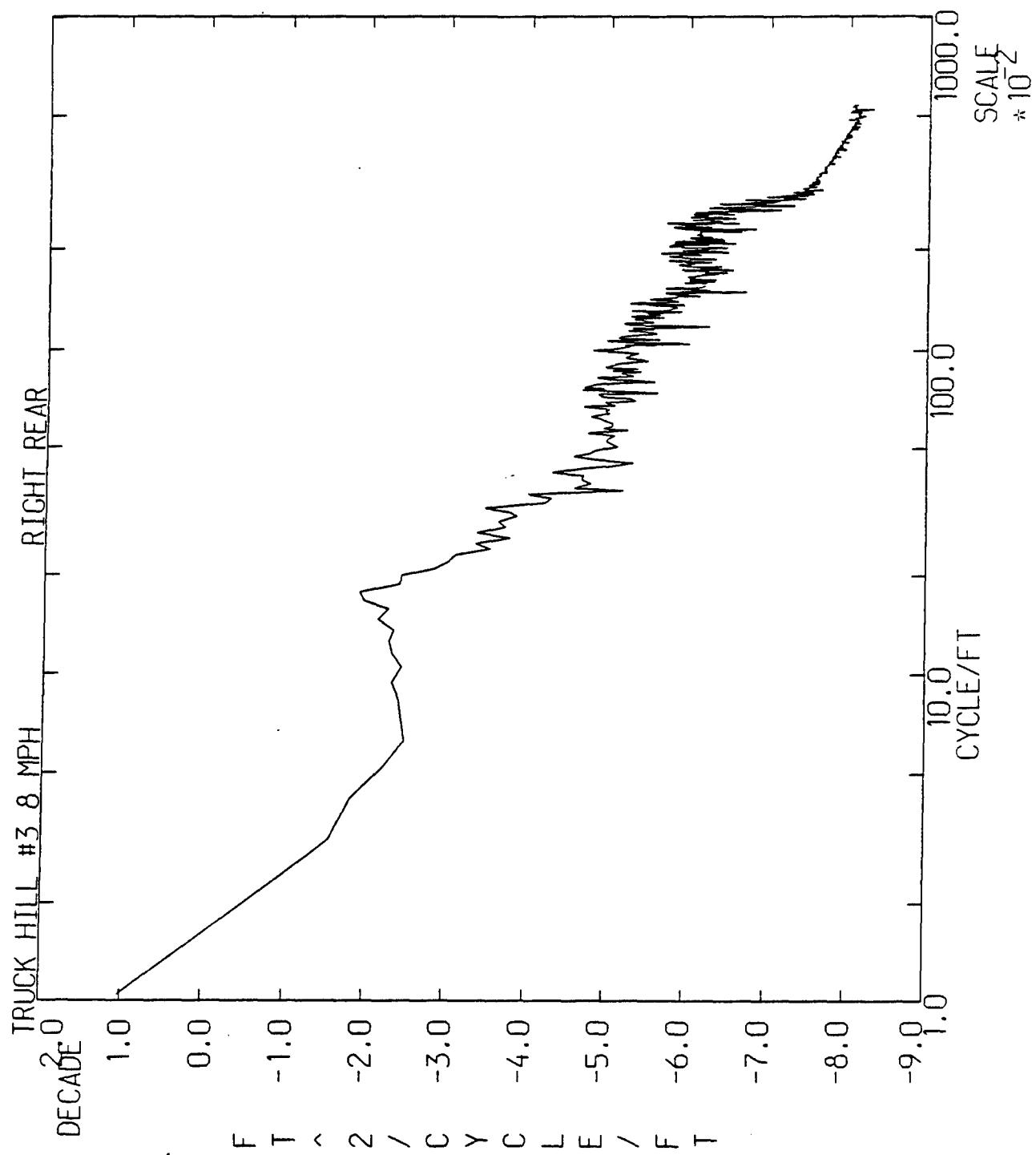


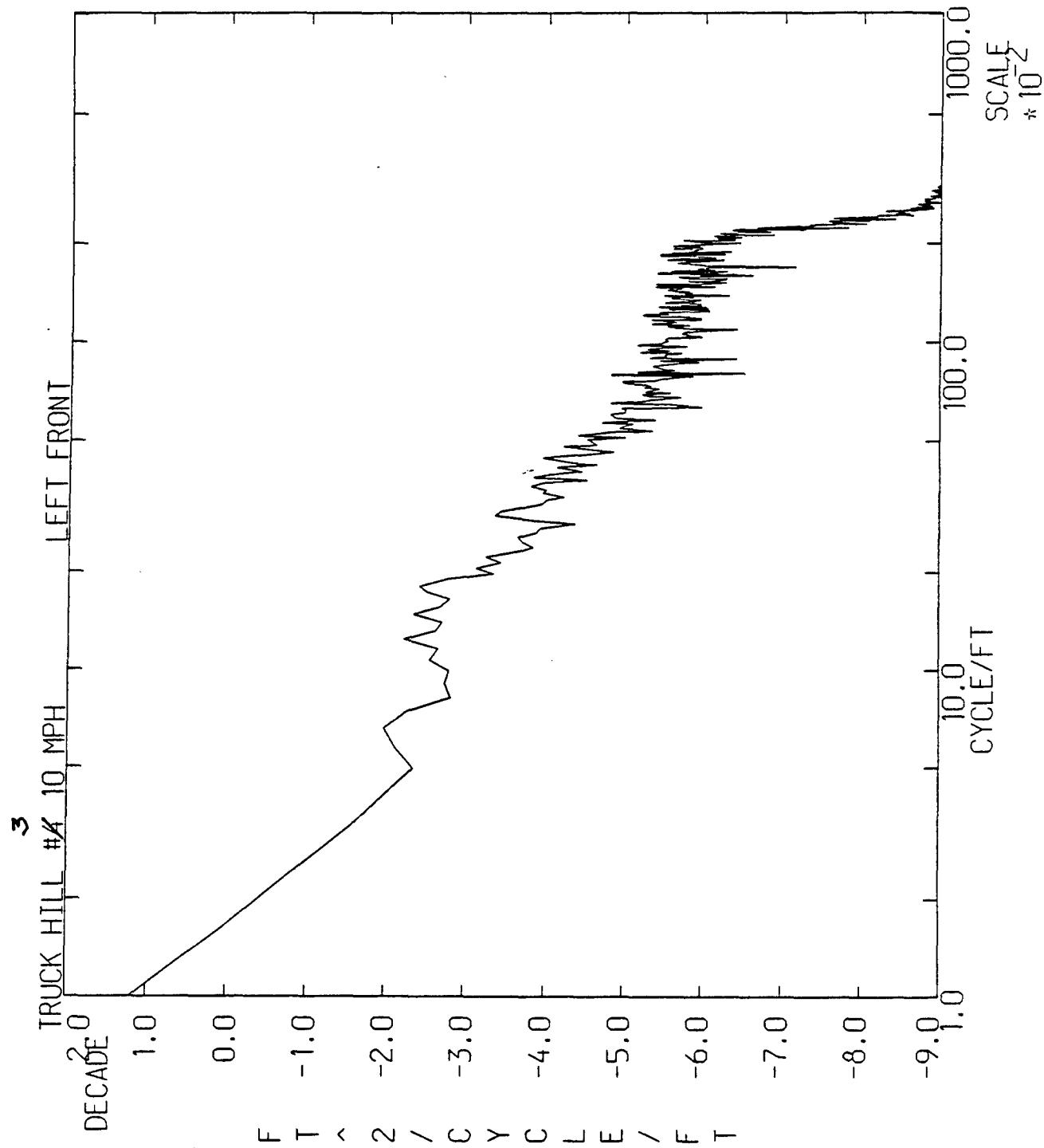


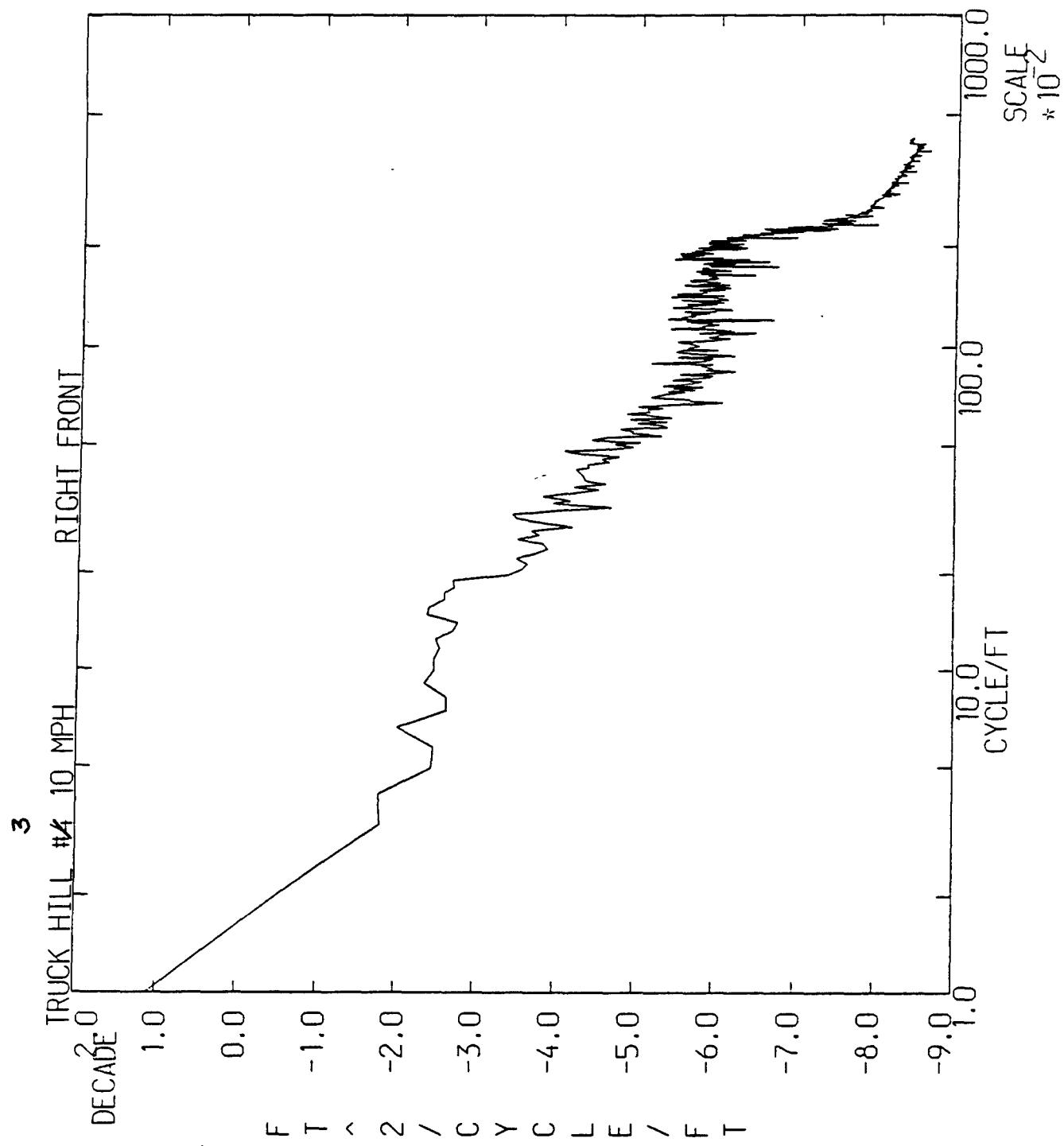
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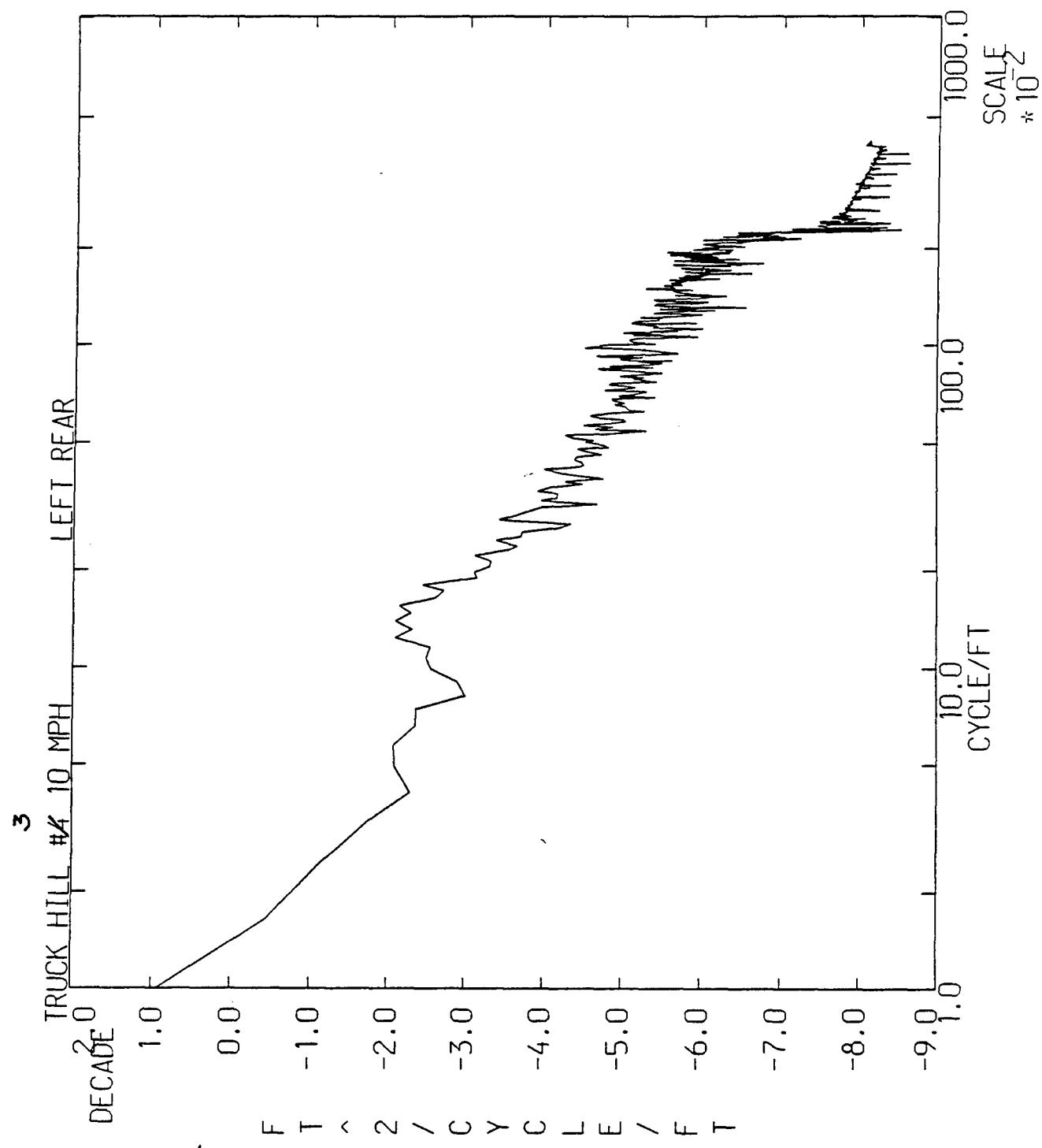


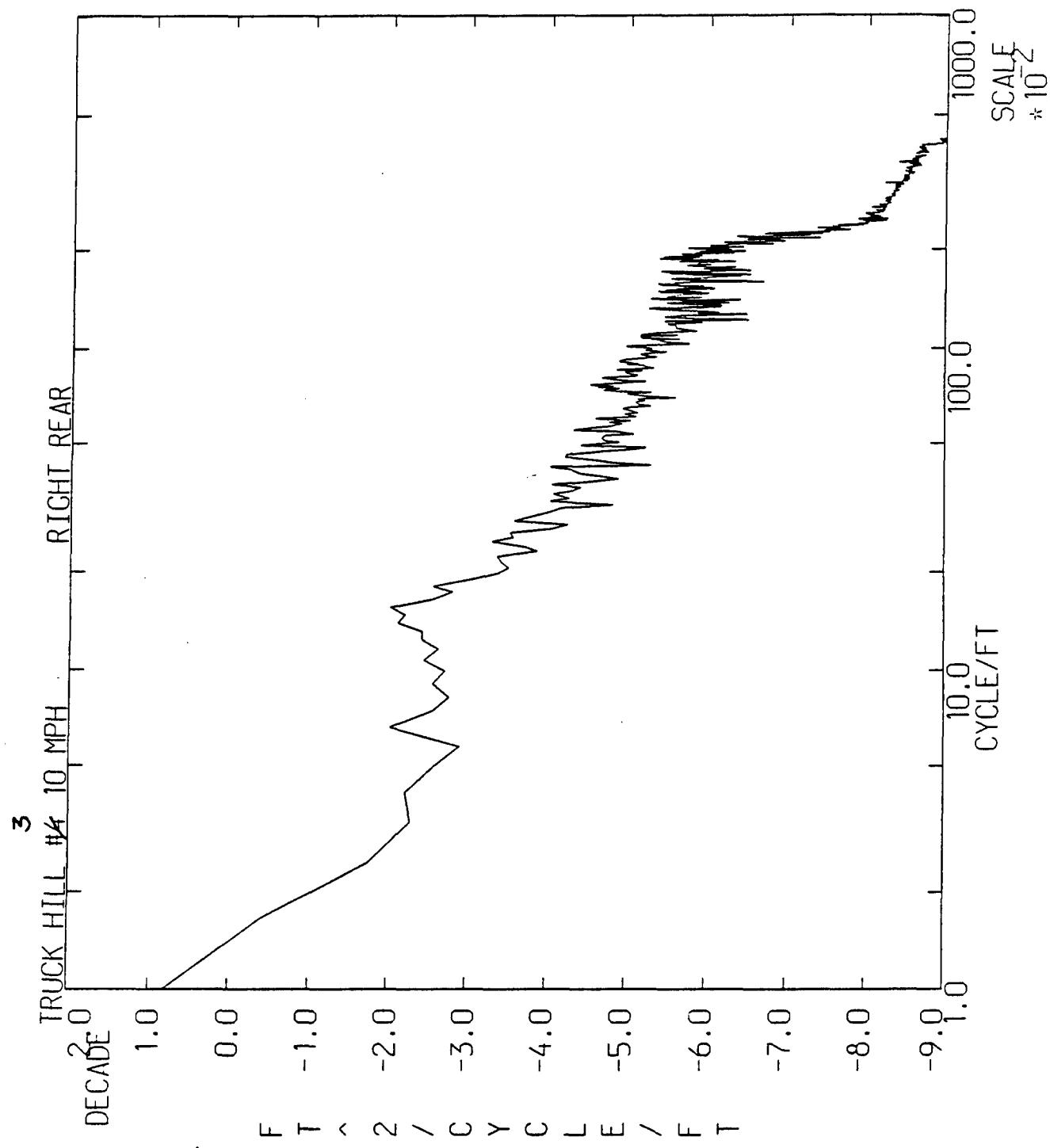












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TRUCK HILL #4

WAVE-NUMBER SPECTRA

2, 4, 6 and 8 MPH

Four (4) curves per speed, one for each DFMV tire, as follows

LEFT FRONT
RIGHT FRONT
LEFT REAR
RIGHT REAR

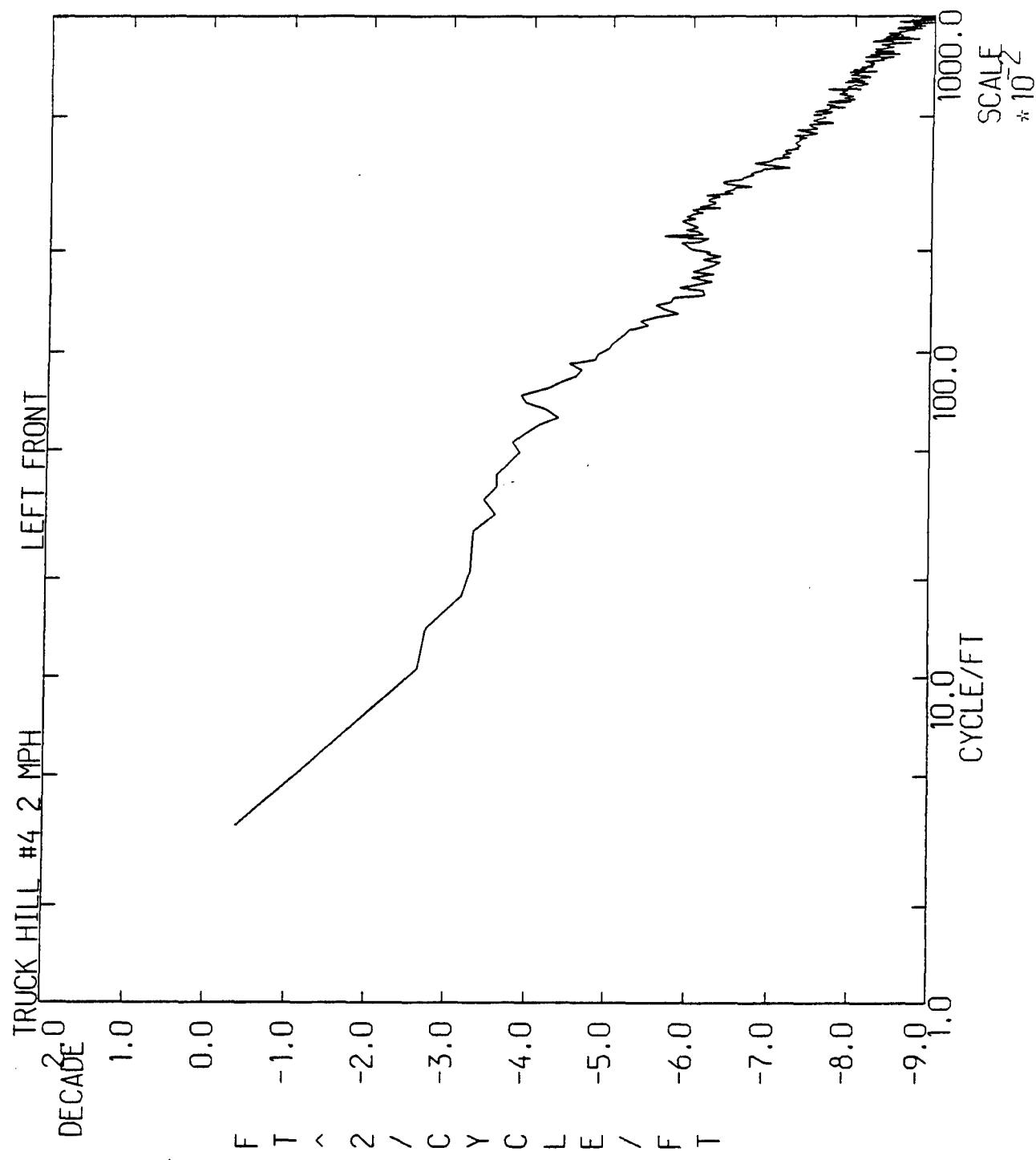
Volume II contains the data for the different DFMV speeds over each YPG course. The data was previously submitted to TACOM in an interim data report, however, the data was not reprocessed with the signal processing considerations discussed in the Volume I report (e.g., in this data, much of the spectral resolution was below the footprint). The wave-number cut-off at the low end of the spectra was limited by the frequency range of the accelerometer, as discussed in the report and shown in the table below. The wave-number cut-off at the high end of the spectrum was limited by the footprint length of the DFMV tire, which was $\approx 1.2 \text{ ft}^{-1}$. These cut-offs were verified through the DFMV front-to-rear coherence plots. Therefore, when comparing plots between different speeds, do not compare the data past these limits. As discussed in the report, the faster speed runs produced the best results at the lower wave numbers.

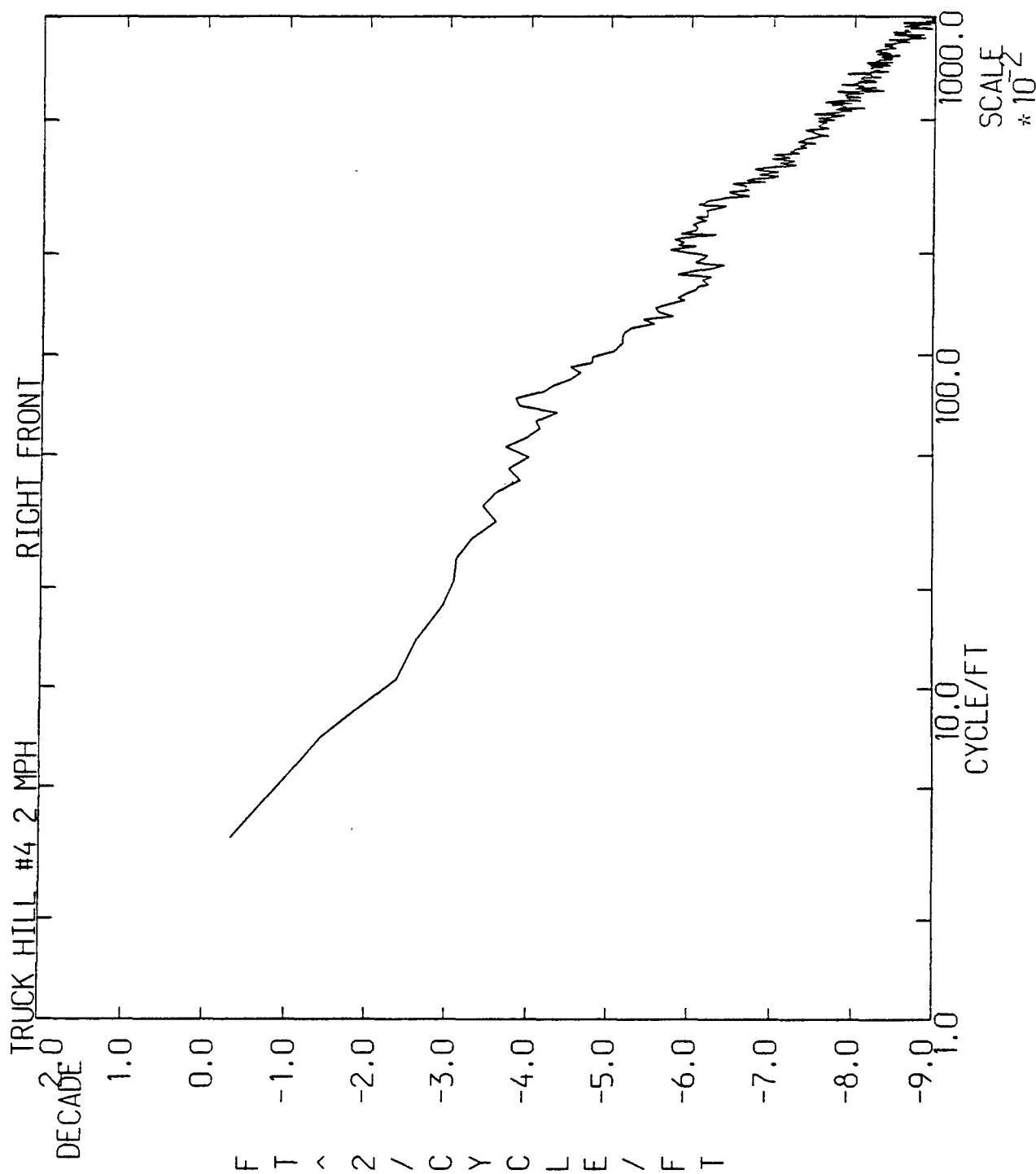
Table 1. DFMV Actual Versus Predicted Wavelength Limits

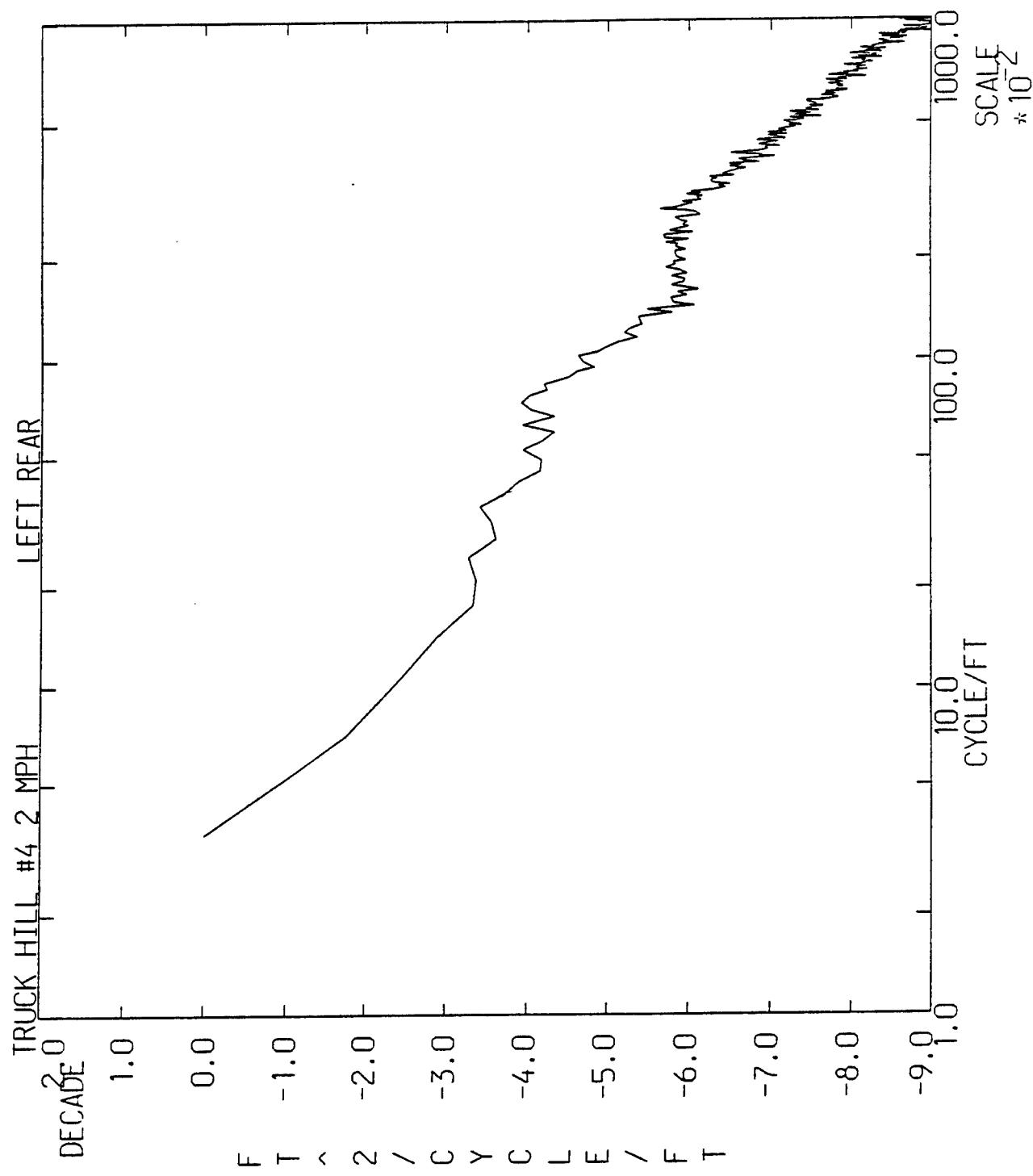
DFMV Speed MPH	Expected Wavelength Resolution*	Actual Wavelength Resolution**
2	60	15
4	120	30
6	180	45
8	240	60
10	300	75

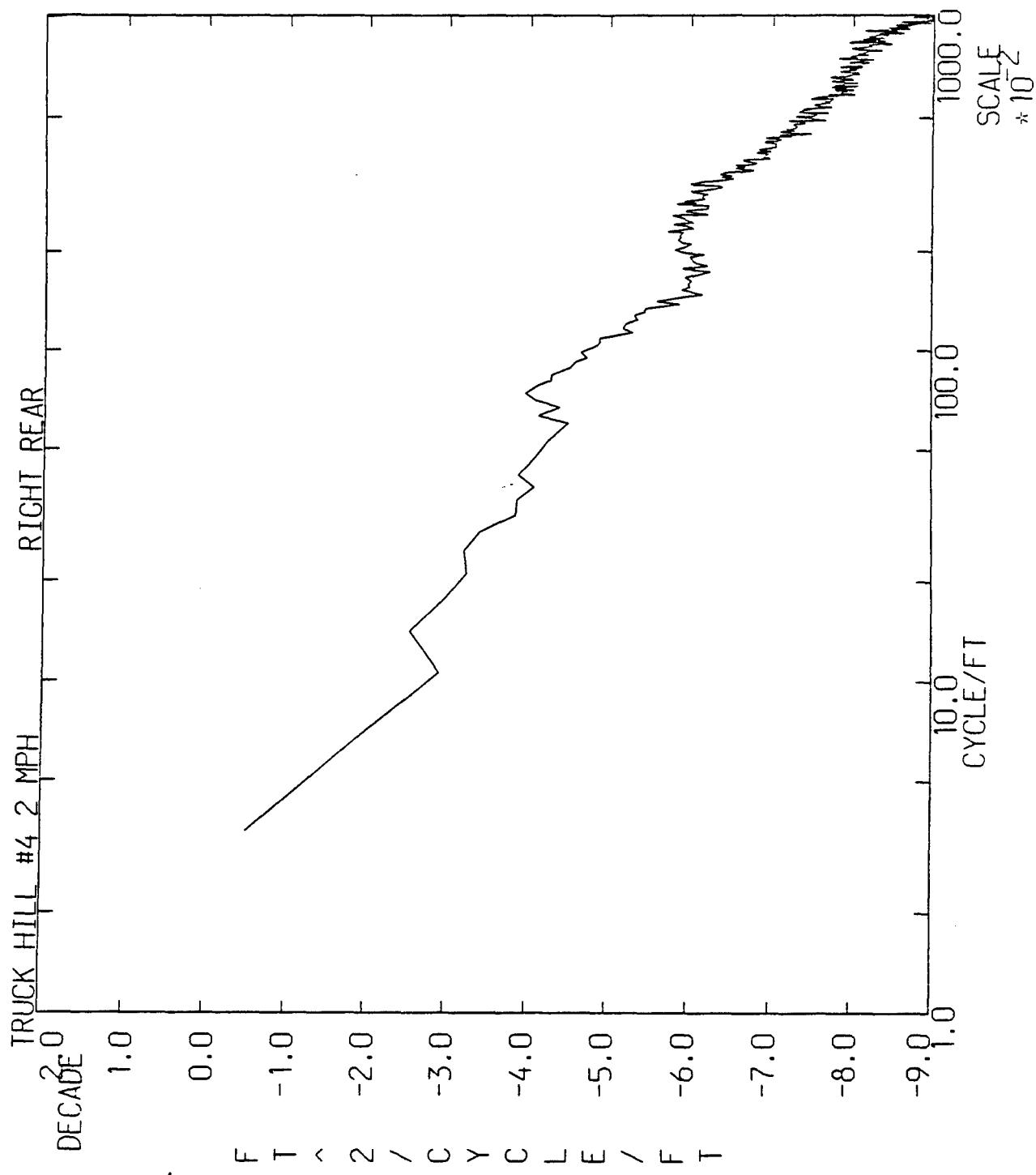
* Based on the advertised low-end frequency range for the accelerometer used

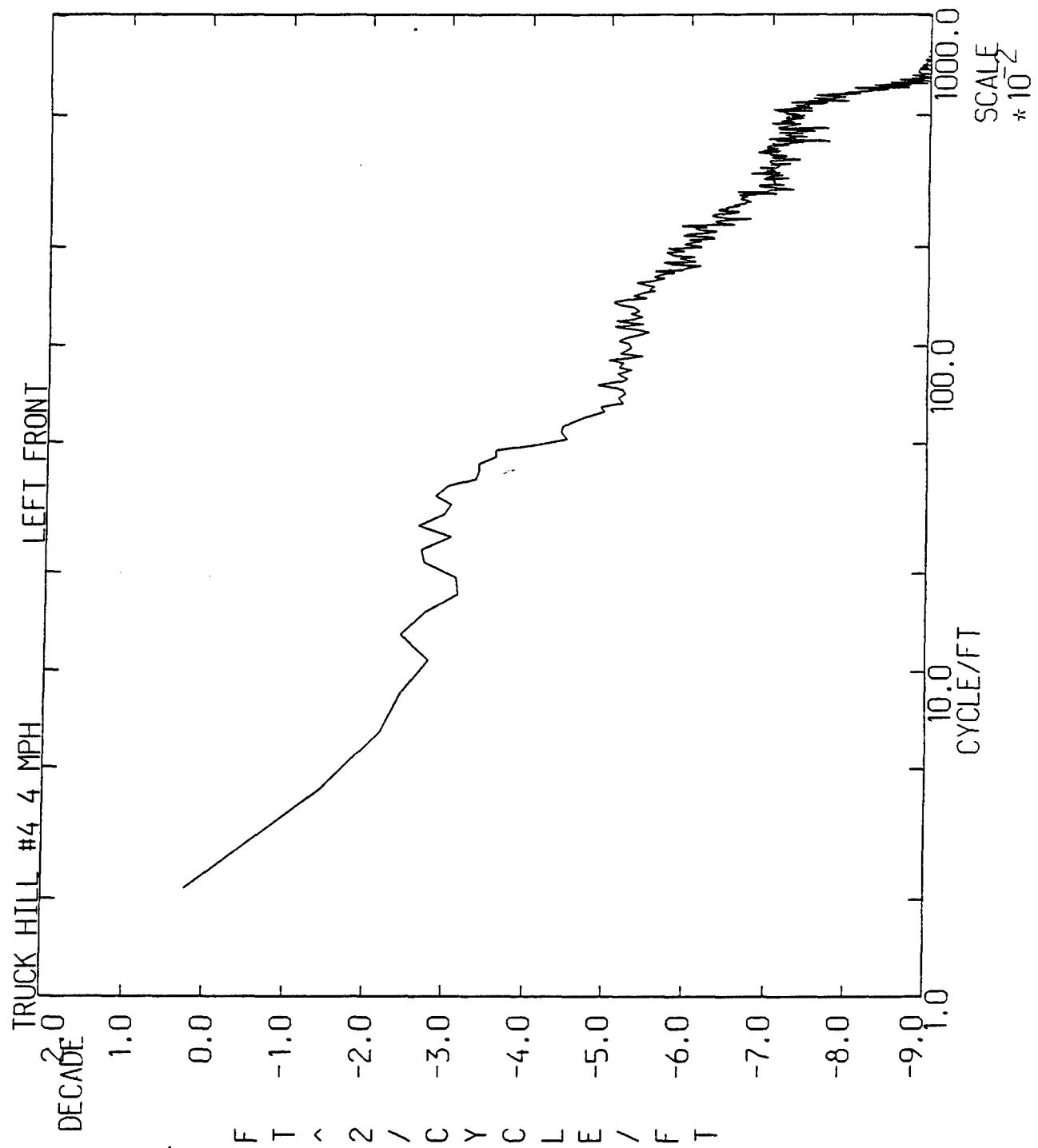
** Based on actual low-end frequency range for the accelerometer used

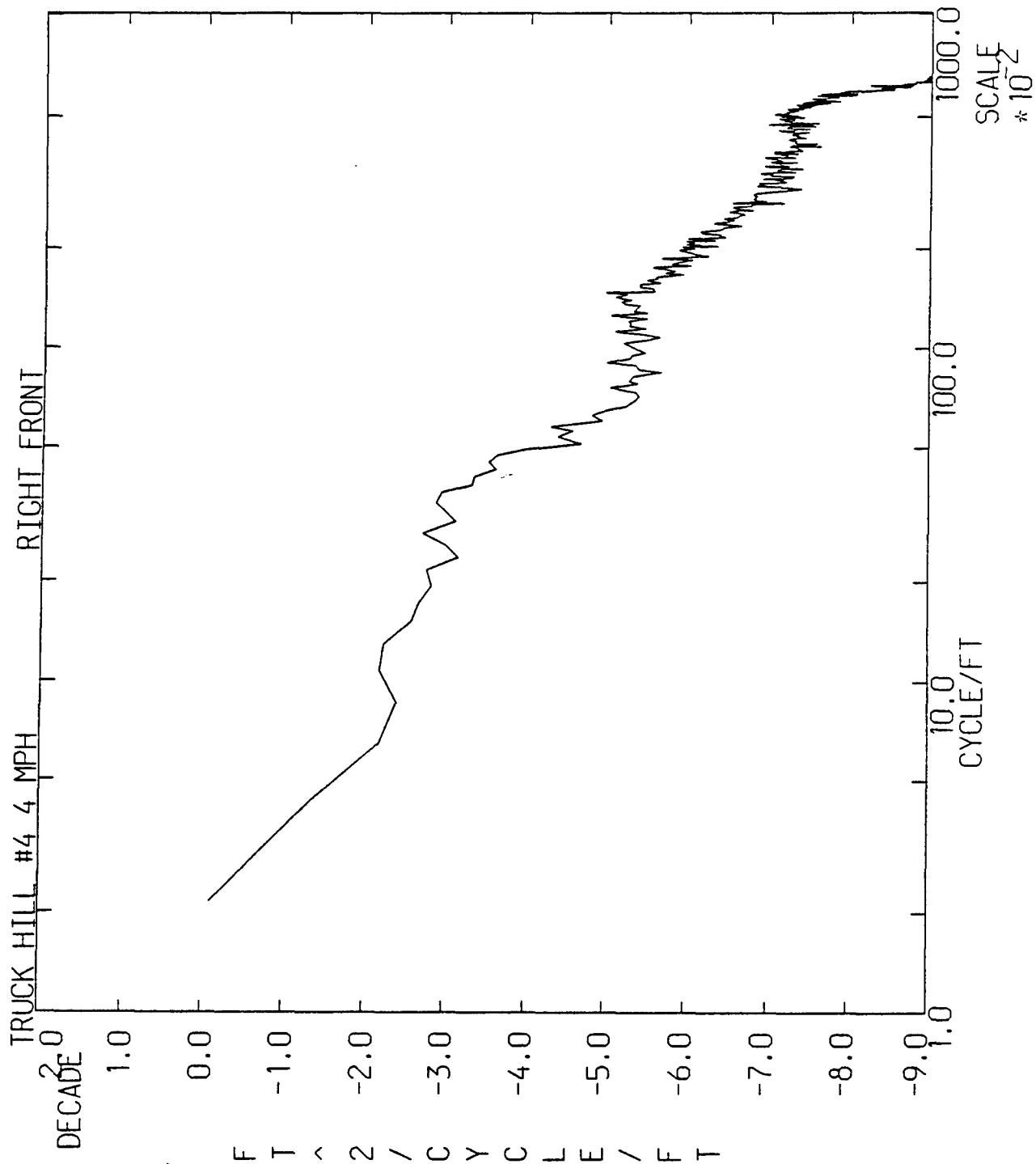


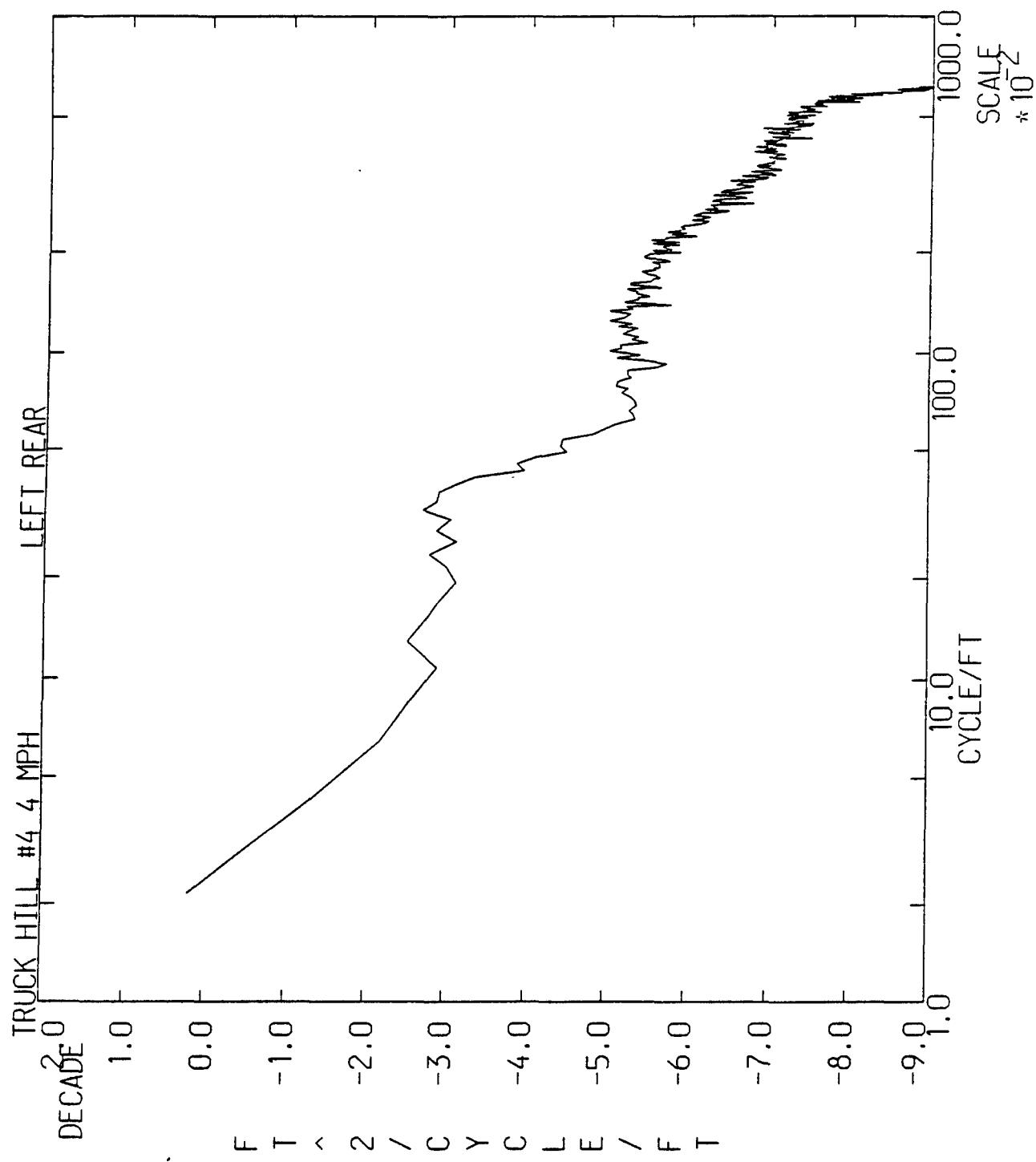


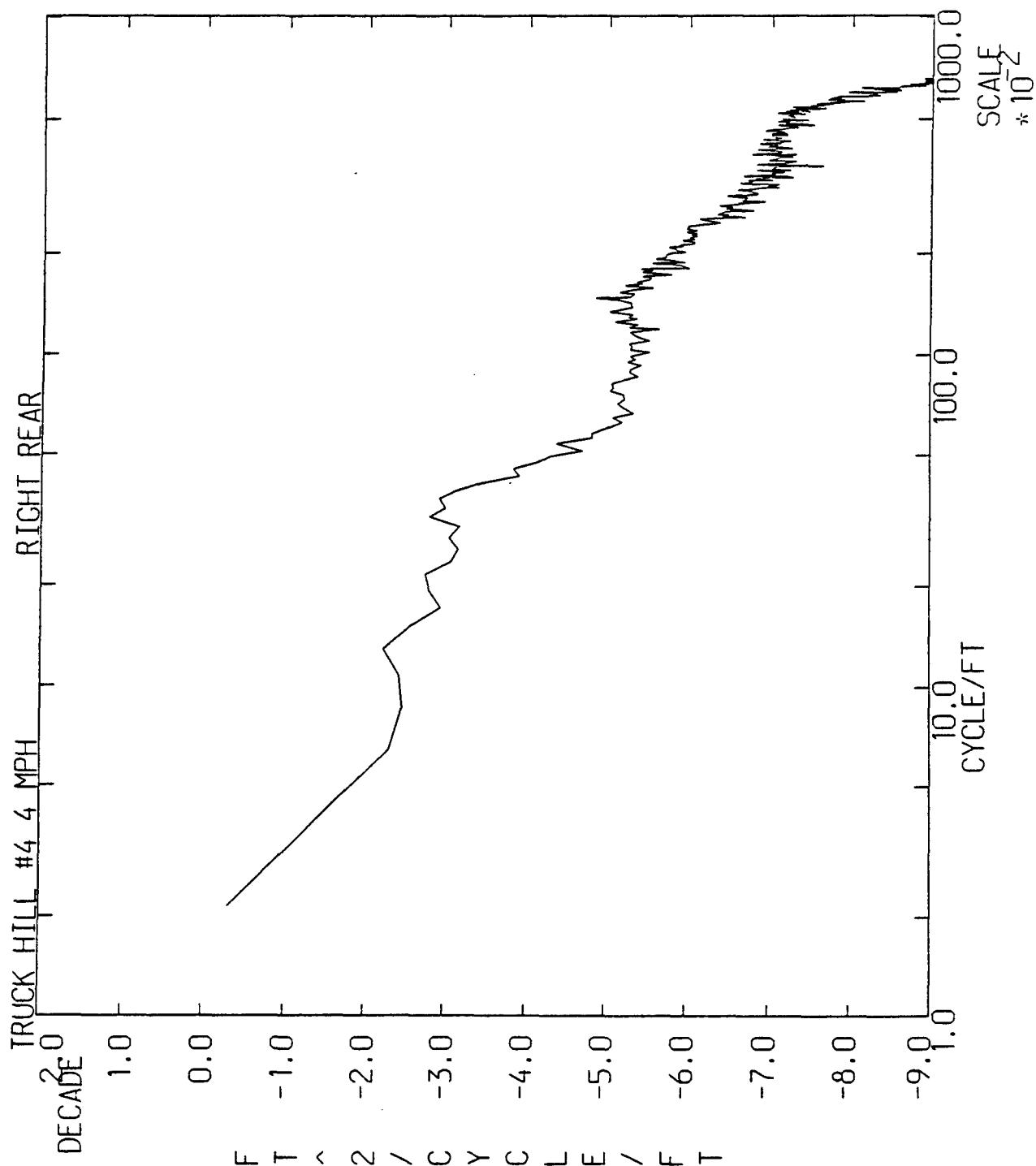


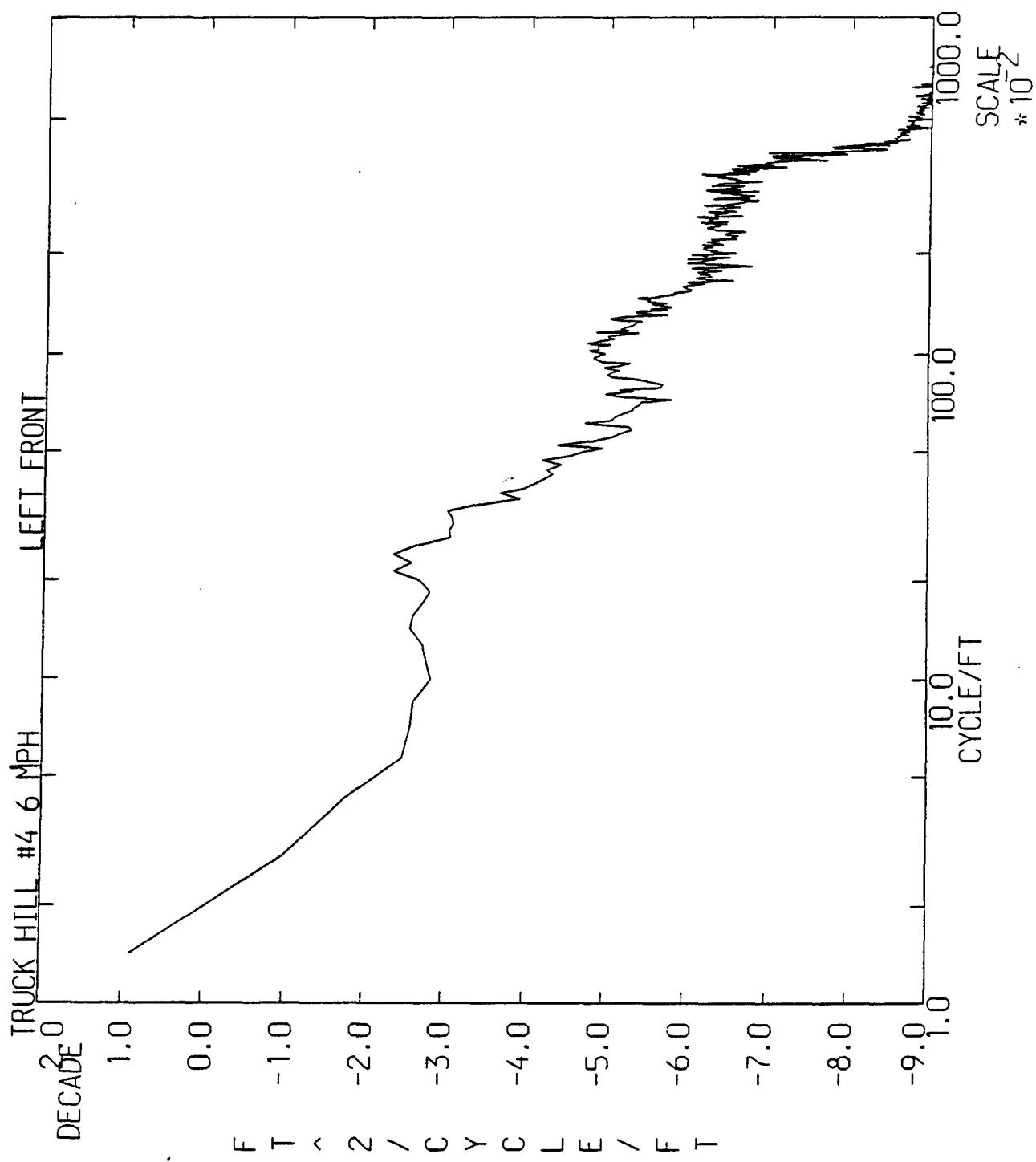


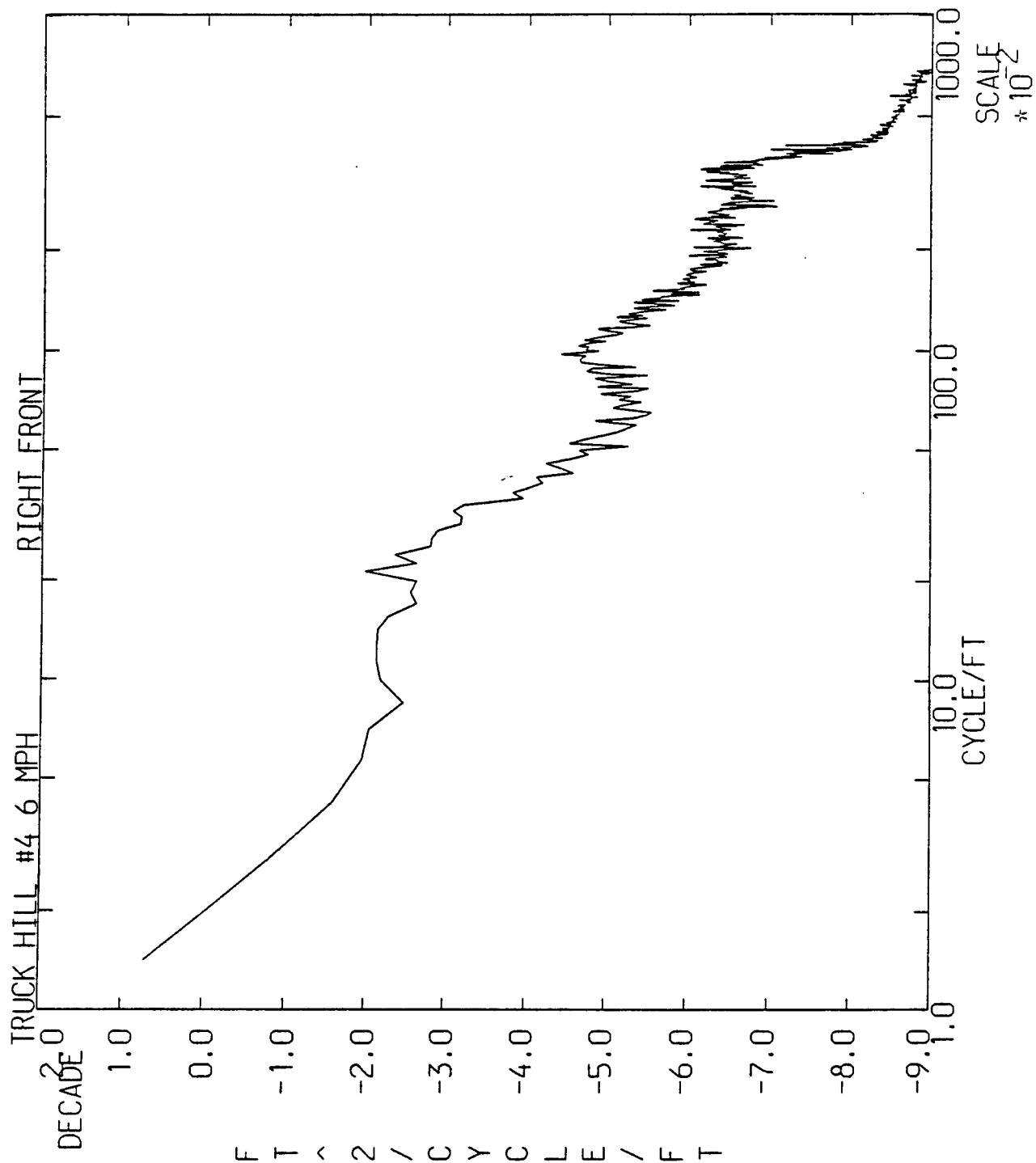


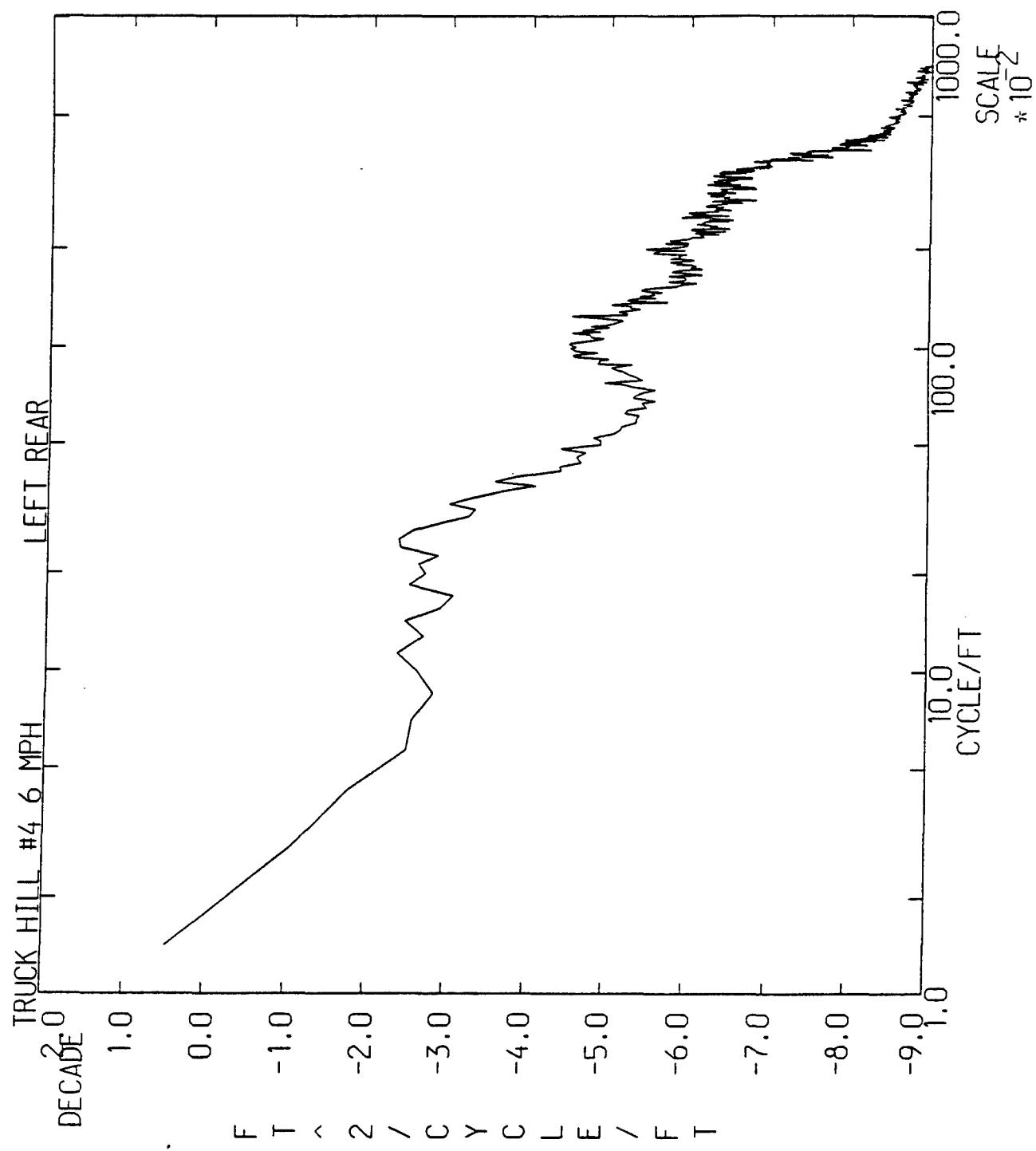












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